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ANNUAL REPORT

OF THE

GEOLOGICAL SURVEY

OF

ARKANSAS

FOR 1890.

VOLUME IV

MARBLES AND OTHER LIMESTONES.

By T. C. Hopkins.

JOHN C. BRANNER, PH. D.

State Geologist.

LITTLE ROCK, ARK.

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OFFICE OF THE GEOLOGICAL SURVEY OF ARKANSAS,
LITTLE ROCK, Dec. 27, 1892.

To His Excellency,
Hon. James P. Eagle,
Governor of Arkansas.

Sir:

I have the honor to submit herewith Volume IV. of my annual report for 1890, and to remain,

Your obedient servant,
JOHN C. BRANNER,
State Geologist.

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PREFACE.

The present report upon the marbles and other limestones of Arkansas is devoted principally to a limited number of geologic horizons, lying north of the Boston Mountains, and between Batesville on the east, and Eureka Springs on the west. The tracing out of the marble beds and the location of the outcrops, the general study of the other limestones, structural features and other work incident upon the construction of a reasonably accurate and detailed map of the region covered by this report have been more than enough to employ all the time of the assistant, to whom the body of the work has been entrusted since 1889. Along with this work, however, Mr. Hopkins has gathered a great amount of valuable information regarding the topography, stratigraphy, paleontology, soils, and other features and resources of that portion of the state which will be brought out in subsequent reports of the Survey.

Some of the waters have been collected and their analyses are given in the report on Mineral Waters (Vol. I., for 1891); the zinc deposits will be reported on in a separate volume now in preparation. The chapter on faults is intended to give only a general idea of the subject as related to North Arkansas, and the details of a few localities at which the faults directly affect the distribution of the marble. Mr. Hopkins' additional observations on faults will be published in subsequent volumes. It may here be added, in regard to the age of the faults spoken of by Mr. Hopkins, that this same system of faults and folds passes southward from the Silurian and Lower Carboniferous areas across the Boston Mountains, and westward into the coal fields of Sebastian county and of Indian Territory. In the southern part of the Carboniferous area the Lower Cretaceous rocks lie unconformably upon the eroded edges of disturbed and faulted Carboniferous beds,

showing that the disturbances took place before Cretaceous times.

Hydraulic limestones and the so-called "onyx" marbles are two subjects properly included under the subject title of this report, which for lack of time and means, have not received the attention to which their importance entitles them. Thus far none of the limestones in North Arkansas have been tested for hydraulic properties, but I have no doubt that such limestones exists there in abundance. All that it has been possible to gather concerning the "onyx" marbles is given in the present report, but the larger subjects have required too much time to leave much for this special class of marbles.

That Arkansas marbles are unknown in the markets is due partly to the lack of information regarding them; partly to a lack of railway transportation in those parts of the state in which the best marbles occur, and partly perhaps to the bad impression gained of Arkansas marbles at Eureka Springs, where a few very poor varieties have been used. Unfortunately the marble bed at Eureka Springs is of no value, and it gives the impression that our marbles are worthless throughout.

As to the amount of marbles in Arkansas, perhaps no statement will convey a more comprehensive idea of it than the statistics of the length of the outcrops delineated upon the maps that form parts of this report.

The marble areas of Arkansas as shown on the map sheets.

	Name of map sheet.	Area of map: Square miles.	Length of marble outcrop in miles.
1.	Batesville sheet	761	198
2.	Mountain View sheet	816	443
3.	Harrison sheet	816	958
4.	Lead Hill sheet	549	358
5.	Carrollton sheet	778	260
6.	Eureka Springs sheet	747	595
	Total	4450	2812

The length of the marble outcrop given in this table is computed from the map; as a matter of fact, it is much less than its real length, for the reason that it has not been possible to

put on the maps all the minor details of the outcrop. In the vicinity of Eureka Springs, for example, the greater sinuosity of the marble bed there shown is due simply to more detailed work; in many other regions the outcrop is just as winding, but it has not been possible to map the entire area in such detail. The actual length of the marble outcrop in the state, therefore, exclusive of that in Washington and Benton counties, where it has no commercial value, is about 3500 miles.

With the present description and delineation of the marbles and marble areas of the state it only remains for us to develop the industries that depend upon such limestones and marbles. It is probable, however, that but little can be done to develop these deposits until the state has better railway facilities. Yet as Mr. Hopkins points out, there are fine exposures of marble within convenient reach of White River. It may also be accepted as a fact that there will be no demand for Arkansas marbles until builders and architects are made acquainted with them, and are assured that they can be obtained in quantity and at convenient prices. The introduction of any new building stone in the market necessarily requires time, because architects prefer stones with which they are acquainted to new and untried ones. The reason for this is that actual tests of a stone are the best guarantees of its qualities, and a stone that has been tried and found satisfactory is always preferred to new and untried ones. For this reason it must not be expected that Arkansas marbles, although quite as good as those from Tennessee, will, at the outset, sell for as high a price; they must make their way into the market at a discount. In this connection it cannot be too earnestly urged upon those who undertake to build up the marble industry in our state to take especial pains to avoid the poorer grades. A few shipments of poor marble from Arkansas will prejudice buyers against the stone for many years to come.

In order to make the report of as much practical value as possible in setting the marble industry on foot, two chapters are devoted to quarrying and the preparation of the stone.

The maps that form a part of the present report show the

entire marble horizon of the state, except that west of range 28, which is shown on the maps accompanying the Washington and Benton county reports. The six map sheets with the present volume are designated Batesville,* Mountain View, Harrison, Lead Hill, Carrollton, and Eureka Springs map sheets. Upon these sheets the outcrops and areal distributions of the several geologic formations treated in the report are laid down with reference to the township and section lines. In making these maps the township sheets of the land office surveys were used as the bases. As every one knows, however, those maps are very defective, and have required a great deal of correcting; the corrections have been made with much care, and the distribution of the formations determined and laid down by reference to land corners, and by meandering from one known point to another, and laying down the geology as it was passed over. Attention should be called to the fact, however, that all parts of these maps are not equally trustworthy, for on account of the difficulty of obtaining checking points on the land lines, they are less detailed in the mountainous and thinly settled regions. On the northwestern part of the Mountain View sheet, for instance, the work was done in less detail, partly on account of the lack of time, and partly because the marble in that area has little economic value.

In the field work for his geological maps sheets, Mr. Hopkins has been aided by Mr. George H. Ashley, in the western part of Boone county, and the northern part of Newton county. Mr. John F. Newson traced out the Fayetteville shale from Mt. Parthenon, Newton county, to Alco, in Stone county, and from Marcella to Batesville, Independence county. Mr. Bert Hoover, aided in locating the Fayetteville shale on the headwaters of Big Buffalo, and on the headwaters of Big Creek, above Mount Judea. Mr. C. E. Siebenthal located the Fayetteville shale east of Batesville, and the base of the Coal Measures, east of Jamestown, on the Batesville sheet.

*The Batesville sheet was published originally with the Survey's Report on Manganese (Vol. I. 1890); it is here reproduced with such additional information as relates to the marble.

The crushing and other tests of the Arkansas building stones given in this report, where not otherwise credited, were made at Cornell University by Prof. Charles B. Wing, now of Stanford University. Most of the chemical analyses when not stated to have been done by some one else, were made in the Survey's laboratory by assistant Dr. Richard N. Brackett; some were made by W. A. Noyes, at Rose Polytechnic Institute, Terre Haute, Ind., and some were made in the chemical laboratory at Stanford University.

The great body of the work represented by the report was done by assistant geologist Thomas C. Hopkins. The thoroughness and faithfulness with which Mr. Hopkins has done his work speaks for itself to every geologist, but I have no hesitation in saying that it speaks in properly emphatic terms only to those of us who month after month, and year after year, have endured whatever has to be endured in working out geology in the mountainous and thinly settled forest-covered regions of the southwest.

To people living in the region described, the Survey is under great obligations; they have not only opened their homes to us in that cordial and hospitable way so characteristic of the people of Arkansas, but they have done everything in their power to help us. We are under especial obligations, however, to Mr. Joseph Hixson, of Mountain View, Stone county, and to Mr. E. J. Rhodes, of Boone county, for their helpful cooperation.

JOHN C. BRANNER,
State Geologist.

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Page

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10. In the table, for "Genievieve" read *Genevieve.*

12. Last word, for "chapters" read *reports.*

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MARBLES AND OTHER LIMESTONES.

BY T. C. HOPKINS.

CHAPTER I.

GENERAL DESCRIPTION OF THE MARBLE AREA.

Geographical position and extent of the marble area.—The marble region of Arkansas is in the north and northwest part of the state, north of 35° 40′ north latitude, and west of longitude 91° 30′ west of Greenwich, north of township line 12 N., and west of range line 4 W. The spherical coördinates of four towns in the area are as follows:*

	West Longitude from Greenwich.			*North Latitude.*		
Batesville	91°	39′	15″	35°	46′	10″
Mountain View	92	7	2	35	51	54
Marshall	92	37	41	35	37	41
Yellville	92	40	57	36	13	37

It includes Marion, Boone, Benton and parts of Independence, Izard, Stone, Baxter, Searcy, Newton, Madison, and Washington counties, and extends north into the State of Missouri.

The entire region is north of the Boston Mountains, and with the exception of portions of Washington and Benton counties is in the upper White River valley. It is commonly known as North Arkansas, the Boston Mountains forming a natural barrier between it and the remainder of the state on the south, while the flood-plains of the Black River bound it on the east.

General topography.—The marble region of North Arkansas

*Obtained directly or by computation from the topographic work of the United States Geological Survey.

forms part of an elevated area that includes also parts of Missouri and Indian Territory. The whole elevated region has been termed the Ozark uplift by Missouri geologists. Prof. Broadhead says it includes an area of 36,000 square miles in the State of Missouri.*

The region was elevated with some faulting and a little folding of the rocks in the marble area; with the exception of small local flexures the strata have a nearly horizontal position with a slight general dip to the south. The entire area has been elevated since Carboniferous times. Since its elevation North Arkansas and a considerable part of Missouri have been deeply eroded by the White River and its tributaries; northwest Arkansas, southwest Missouri, and northeast Indian Territory by the Illinois River and its tributaries.

The Boston Mountains form an irregular wall along the south side of the deeply eroded area. That the heavy strata which form these mountains at one time extended far north of the present position of the mountains is shown by the numerous outliers or isolated peaks scattered over the region and corresponding stratigraphically to the parent range.

Peneplains.—Owing to the greater durability of some of the strata, the deep erosion has produced two general plateaus or peneplains which merge into each other in many places; the mountain level ranges from 1000 to 2200 feet above tide; the general peneplain varies from 500 to 1000 feet in elevation.

The first of these, the mountain plateau, includes but a comparatively small part of the area mapped. It is found on the spurs and outliers of the Boston Mountains, which occur along the southern part of each of the map sheets, except the Lead Hill sheet, on which it does not appear. The largest area of this elevation is in the Gaither Mountain and its spurs, which is the most northern projection of the Boston Mountains in the state. The surface on this plateau is in the Lower Coal Measures. The second or general peneplain comprises possibly the greater part of the entire region, and its rock surfaces are mostly the sandstones or cherts of the Lower Carbonif-

*American Geologist, January, 1889.

erous; while there is a secondary plateau in the north part of the Lead Hill sheet, as well as on the greater part of the area north of White River, on rocks of the Lower Silurian age. The Pleistocene and recent area east of Batesville is very low, nearly all being subject to overflow.

Elevations.—The following elevations of different points over the area will give a general idea of the diversified nature of the country and serve as convenient points of reference:

Elevations above sea-level.

Locality.	*Feet.*
Barren Fork (1)	700
Batesville (5)	268
Bellefonte (3)	1105
Big Flat (1)	1250
Blue Mountain, south of Marshall (1)	1700
Boat Mountain, southwest of Valley Springs (3)	2200
Burlington (4)	1483
Compton (3)	2210
Dinsmore (3)	1520
Elixir (1)	1000
Eureka Springs, Crescent Hotel (3)	1463
Francis post-office (3)	1105
Gaskins (5)	1034
Harrison (4)	1045
Hill Top (3)	2210
Hottentot (3)	1400
Lead Hill (1)	650
Lone Rock (1)	750
Marble (3)	1300
Marshall (1)	1036
Moorefield (5)	312
Mountain View (1)	730
Omaha (4)	1373
Oregon (3)	1275
Panther Mountain, top of (1)	1550
Pilot Mountain, west of Valley Springs (3)	2075
Powell (1)	750
Rally Hill (1)	1100
Rule (3)	1320
Batavia (3)	1545
Beaver (The Narrows) (5)	934
Berryville (3)	1275
Blue Mountain, south of Mountain View (1)	1350
Boat Mountain, Carroll county (3)	1523
Bruno (1)	950
Buffalo City (1)	400
Carrollton (3)	1280
Cushman (5)	775
Dry Fork post-office (3)	1400
Eureka Springs, railway station (5)	1143
Flippin (1)	650
Garfield (5)	1519
Green Forest (3)	1420
Hickory Valley (1)	591
Hindsville (2)	1300
Huntsville (2)	1300
Leatherwood (5)	942
Lost Mountain, top of, (Searcy county) (1)	2200
Matney's Knob (1)	1250
Mount Hersey (1)	750
Oak Hill post-office (3)	1123
Omega (3)	1360
Osage (3)	1390
Peel (1)	850
Piney (3)	1580
Point Peter (1)	2000
Puckett (2)	1076
Rogers (5)	1385
Silver Springs (Spg.) (2)	1085

Locality.	*Feet.*	*Locality.*	*Feet.*
Sulphur Rock (5)	316	Valley Springs (3)	1075
Waldon (5)	976	Watkins (3)	1245
Western Grove (1)	1100	Willcockson (Marble City) (3)	945
Winona Springs (3)	1283	Yellville (1)	600

(1.) Determinations based on the topographic work of the U. S. Geological Survey (aneroid and cistern barometers).

(2.) Elevations based on aneroid measurements checked on the railway level at Rogers, and believed to be accurate within 50 feet.

(3.) Elevations checked on the railway level at Eureka Springs, and believed to be accurate within 50 feet.

(4.) The elevation of Burlington and of Omaha are by spirit level on a railway survey from Bull's Creek, Missouri, to Dardanelle, Arkansas. The same survey gives the elevation for the valley east of Harrison as 1100 feet.

(5.) Railway spirit levels.

Mountains.—The Boston Mountains* extend in a direction a little north of west from the White River in Independence county into Indian Territory. The region as a whole is an elevated plateau deeply eroded on the margins. The mountains are wholly mountains of erosion, and are but the remnants of a great mass of sediments that at one time covered all the northern part of the state west of the St. Louis, Iron Mountain and Southern Railway. They present a bold but very winding escarpment on the north face, with numerous outliers and spurs jutting out toward the north, which are shown on the map, by the isolated and peninsula-like projections of the Millstone grit formations along the southern borders of the different map sheets accompanying this report. The mountains form the divide between the Little Red and Arkansas Rivers on the south and White River on the north, the northern spurs forming the divides between the southern tributaries of White River. The divide between some of the White River and some of the Red and Arkansas River tributaries is very narrow, scarcely wide enough for a wagon road, and in a few places these narrow divides have been eroded much below the general level of the mountains, thus forming low gaps in the dividing ridge.

*The eastern end of the Boston Mountains, from Marshall to White River, is sometimes called the Blue Mountains, but as the term Boston Mountains is more commonly used as applying to the whole system, it is so used in this report.

On the south side the mountains are as deeply eroded as on the north side, but owing to the south dip, which becomes more marked south of the mountains, the slopes are not always so precipitous.

Some of the more prominent of the numerous outliers to the north which mark the former position of the mountain escarpment are Cow, Roper, Round, and Panther Mountains, in Stone county; Pilot Mountain, in Searcy county; Lick, Pinnacle, Sulphur, and Fodder Stack Mountains, in Newton county; Pilot Mountain, Pilot Knob, Boat, and Round Mountains, in Boone county; the numerous peaks west, northwest, and southwest of Carrollton, and Swain, Pond, and Grindstone Mountains, in Carroll county; Poor, Ellis, and Blansett Mountains, in Benton county; and Keefer Mountain, in Madison county. Many of the peaks above mentioned are capped with the Millstone grit of the Lower Coal Measures, while the others extend nearly to the top of the Lower Carboniferous. There are numerous other peaks north of the ones mentioned which are almost as prominent topographic features, but are lower in the geologic series. Such are Sugar Loaf Mountain, in Stone county; Naked Joe, Matney's, and Perry's Knobs, in Baxter county; Mount Ephraim, Bald Jesse, Hall's, and Lee's Mountains, in Marion county; Sugar Loaf Mountain near Lead Hill, in Boone county; Pilot Knob, Brushy Mountain, and the Three Sisters, north and east of Berryville, in Carroll county. Nearly all the mountain peaks above named are well known locally, and are familiar landmarks for many miles around.

Prairies, barrens, and flats.—The face of the country is so diversified by the numerous watercourses that no large areas of level country occur west of the Pleistocene area in the eastern part of the region. The ridges as a rule are narrow, but occasionally spread out into rolling tracts a few miles in width. There are strips of bottom land along the larger streams, but as a rule the valleys are narrow. There is an irregular rolling strip along the base of the north escarpment of the mountains varying from a few yards to a few miles in width. Besides the one mentioned a number of small level or rolling

tracts occur in different parts of the region, and are known as "prairies," "flats," or "barrens."* Some of the best known of these comparatively level areas are Marshall's, King's, Huzza, and Baker's Prairies, all in the Crooked Creek valley; Cowan Barrens on the south side of Crooked Creek, and Flippin Barrens on the north side; "The Barrens," in Independence county, west of Batesville; Big Flat, between Big and Sylamore Creeks; Ham Flat and Anderson Flat, between Clear and Tomahawk and Hampton Creeks; Oregon Flat, on the north side of Crooked Creek; and numerous "post-oak flats" in different parts of the region.

Hydrography.—With the exception of parts of Washington and Benton counties, White River with its numerous tributaries drains the entire marble area. This stream takes its rise in the southern parts of Washington and Madison counties. From the confluence of the Main, Middle, and West Forks the river flows in a very winding but in a general east of north course to the state line, north of Eureka Springs in range 26 W., and after making a big bend northward into Missouri, it returns to the State of Arkansas, in Boone county, in range 19 W., whence, after looping several times across the state line, it flows in a southeasterly direction to the Mississippi River.

The chief affluents of White River in this region are Black River, North Fork, Buffalo River, Crooked Creek, King's River, and War Eagle Creek.† Other large but less prominent tributaries are Polk Bayou, Lafferty Creek, Rocky and Little Rocky Bayous, Sylamore, Livingston, Piney, Jimmy's, Music, Lower Sugar Loaf, Upper Sugar Loaf, Bear, Long, Leatherwood, Butler, Big Clifty, Little Clifty, Brush, and Richland Creeks. Besides these, there are many smaller creeks and a

*The tracts erroneously called "barrens" are all very fertile and in a high state of cultivation. They were originally barren of timber, and this fact gave rise to the name "barrens." Where not under cultivation, they are now covered with a thick growth of black-jack and post-oak.

†Little Red River is a large tributary draining the south slope of the Boston Mountains east of Marshall.

great number of ravines, which at ordinary seasons are dry watercourses, but in time of heavy rains pour great volumes of water into the river. Each tributary has its minor tributaries, and they all terminate in a fan-like array of watercourses, which gives a drainage map a marked dendritic appearance. This is especially prominent in the vicinity of Eureka Springs and on each side of the Crooked Creek valley.

White River is navigable at nearly all seasons of the year as far as Batesville, and, except in time of low water, by small steamers as far as Buffalo City (Winnerva) at the mouth of Buffalo River. In time of high water small steamers run as far as Forsythe, Missouri. From Batesville to the mouth, the current of White River is sluggish and its course is through a low alluvial region. From the head of White River to Batesville the current is rapid and the stream flows through a narrow winding rocky valley, bordered by precipitous bluffs which in a great many places rise abruptly from the water's edge for several hundred feet. So numerous are these perpendicular bluffs that one can find but few points on White River above Batesville where one or more of them are not in sight. They occur on the outside of the curves in the river, there being generally a narrow strip of alluvium opposite the bluff on the inside of the curve. The most prominent and picturesque of these bluffs are Penter's Bluff, the lowest one on the river, 485 feet high; Hidden Creek Bluff, 360 feet high; White Bluff, 360 feet high; and Stair Gap Bluff, 600 feet high. They are composed mostly of limestone and are partially covered with a scraggy growth of cedar which renders them very picturesque.

On Buffalo River through Newton and Searcy counties the bluffs are even more numerous and prominent than on White River. The stream is more winding, the valley narrower, and in Newton county both Big and Little Buffalo Rivers cut deep narrow channels through the mountains which here extend farther north than elsewhere in the region, and the bordering hills are higher than they are along White River. While the bluffs rarely rise more than 400 or 500 feet perpendicularly from the water, so steep is the slope above the cliff that the

top of the hill, within a half a mile or a mile from the river, attains a height of 1300 to 1400 feet. On Big Buffalo River between its confluence with Little Buffalo River and Boxley the saccharoidal sandstone of Silurian age forms the most prominent feature of the lower bluffs, and the Millstone grit the most prominent feature of the upper bluff near the top of the mountains.

Owing to the great number of the streams and their rapid fall, the water-power that might be obtained from them is almost unlimited. The difficulty of controlling it is the chief obstacle to its utilization, for in times of a freshet dams and other improvements are often destroyed by the great volume of water. Buffalo River, for example, has been known to rise sixty feet in one or two days. For this reason but little use is made of this enormous power on the larger streams; it is utilized, however, on many of the small streams. A large number of waterfalls, from five to forty feet in height, occur near the heads of the smaller streams, and these in the aggregate furnish a vast power free from the destructive effects of the freshets of the larger streams. The origin and utilization of these falls will be spoken of in subsequent chapters.

White River and all its tributaries are remarkable for their clear waters. Henry Schoolcraft in his reconnoissance of this region in 1819 says of White River: "Its waters, unlike most of the western rivers, are beautifully clear and transparent, being wholly made up of springs which gush from the flinty hills that are found for more than half its length, within a few miles of, often immediately upon its banks."*

G W. Featherstonhaugh, United States Geologist, in his report of this region in 1835, says: "This stream (White River), which is very little known in the Atlantic States, is one of the most important and beautiful rivers in the United States."†

The remarkable transparency of the water is due to the character of the geologic formations. The larger part of the

*"A View of Missouri and Arkansas." H. R. Schoolcraft, 1819, p. 248.

†Geological Report of the Elevated Country Between the Missouri and Red Rivers by G. W. Featherstonhaugh. Washington, 1835, p. 57.

ON BIG BUFFALO RIVER.

watercourses is in the chert, limestone, and saccharoidal sandstone, none of which furnishes fine sediment, and all of which have a high specific gravity. The effect of the kind of rock on the clearness of the water is shown in ascending the streams which head in the shaly sandstones and shales of the higher formations and flow over the chert, limestone, or saccharoidal sandstone in their lower courses. In such cases the upper part of the stream, which should be the clearest because nearest the springs, is the part containing the most sediment; while the lower part of the stream in the heavier and coarser grained rocks is remarkably clear. This is probably due in large measure to the lime in solution, which tends to flocculate the fine sediment, thus causing it to settle; and the lime itself adds to the transparency of the water. The springs are described elsewhere in this volume.

Stratigraphy.—With the exception of a small area of Pleistocene gravel east of Batesville, the rocks of North Arkansas belong entirely to the Paleozoic system, and, with the possible exception of the Eureka shale, to the Lower Carboniferous and Lower Silurian series

The names of the different formations in the areas under discussion are local geographic or descriptive terms, and no attempt has been made to correlate them with formations elsewhere, except in a very general way. In comparing the accompanying general section with one in Missouri, Tennessee, or Alabama, many striking resemblances appear.*

The terms, with the exception of the St. Joe marble, have all been used in the report on Washington county,† and in the Manganese report of the Batesville region,‡ and the different formations described as they appear in these two localities.

Washington county is on the western border of the state, and the Batesville manganese region is on the eastern border

*See first and second reports of the Geological Survey of Missouri, by G. C. Swallow, 1855; Geology of Tennessee, by James M. Safford, 1869; and Bulletin No. 4, of the Geological Survey of Alabama, 1892.

†Annual Report of the Geological Survey of Arkansas for 1888, Vol. iv.

‡Annual Report of the Geological Survey of Arkansas for 1890, Vol. I.

General Classification of the Rocks of North Arkansas.

System.	Series.	Group.	Correlations.*	North Arkansas.	Maximum thickness—Feet.
Carboniferous or Pennine	Pleistocene	....	....	....	75
	Coal Measures or Pennsylvanian	....	....	Millstone grit	400
	Lower Carboniferous or Mississippian	Boston (Genievieve) †...	"Chester," "St. Louis," "Warsaw.".........	Kessler limestone	250
				Coal-bearing shale ...	
				Pentremital limestone	
				Washington shale & sandstone	
				Archimedes lime stone	80
				Shaly sandstone and shales	200
				Marshall shale...	250
		Osage	"Keokuk" ..... "Burlington" ..	Batesville sandstone	170
				Fayetteville shale	300
				Wyman sandstone	
				Boone chert and limestone, including the St. Joe marble	370
			"Black shale" ...	Sylamore sandstone	40
				Eureka shale	50
Devonian ...	....	....	....	Wanting?	
Silurian	Upper Silurian.	....	....	Wanting?	
	Lower Silurian.	....	"Nashville and Trenton" of Safford.	St. Clair limestone (marble)	155
				Izard (blue) limestone	280
				Saccharoidal sand stone	1700
				Magnesian limestones.	
				Chert ..	
				Sandstones, etc..	
Total	....	....	....	....	4320

*The correlations are based on the paleontologic work of Dr. H. S. Williams, and with the exception of Boston for Genievieve, are the terms used by him in his correlation paper—Bulletin No. 80, of the United States Geological Survey.

†The State Geologist proposes the name Boston for this group of rocks owing to their great development along the Boston Mountains in Arkansas.

of the Paleozoic area; the area described in the present volume includes all the intervening territory. Some of the formations given in the table have not been identified outside of Washington county or its immediate vicinity.

The general section shows the maximum thickness of each formation in the area under discussion. The measurements are all barometric, except the bottom one, the Calciferous sandstone series, which is taken from a deep-well section at the Southern Mine near Cushman.

The Silurian rocks are represented in the eastern part of the area by two heavy beds of limestone (the Izard and the St. Clair) which do not occur in the western or northern part of this area. Below the Izard limestone the Silurian area is characterized by saccharoidal sandstones, dolomites, chert, siliceous and magnesian limestones. Sufficient detailed work has not yet been done on these various beds to classify them except lithologically.

The heavy bed of saccharoidal sandstone which occurs immediately underneath the Izard limestone, or in the absence of the limestone at the top of the Silurian rocks, is topographically one of the most prominent beds. The siliceous dolomites are the most abundant and make up the greater part of the rocks below the saccharoidal sandstone. The Silurian cherts are denser than the Boone chert of the Lower Carboniferous, and they occur more commonly in nodular and lenticular masses.

The Lower Carboniferous series is characterized by limestones, chert, sandstones, and shales. The predominating bed is the chert and cherty limestone at the base, which covers a large part of the Lower Carboniferous area. Other limestones (Archimedes, Pentremital, and Kessler) occur at a higher level, but in only a few places are they exposed over an area of any considerable extent. The alternating beds of sandstones and shales vary greatly in thickness in different parts of the area. The Batesville sandstone overlying the chert, from which it is separated in most places by the Fayetteville shale, is the most

persistent, has the greatest extent and the greatest economic value.

In the area under discussion the only formations above the Lower Carboniferous are the Millstone grit of the Lower Coal Measures, and a small Pleistocene area east of Batesville.

Each of the formations above mentioned is described in detail in subsequent chapters.

PART I.—LIMESTONE.

CHAPTER II.

The Composition and Origin of Limestone.

THE COMPOSITION OF LIMESTONE.

Chemical composition.—Theoretically limestone has a definite composition; practically, however, it is rarely found pure, being often combined with so many impurities as to make any classification an arbitrary one. Thus the siliceous sand and limestone may be so proportioned that one can with equal propriety call it an arenaceous limestone or a calcareous sandstone, or it may be clay, when the rock will be an argillaceous limestone or a calcareous shale. Limestone is essentially a carbonate of lime ($CaCO_3$), that is, a compound of the oxide of the metal calcium (CaO) with carbonic acid gas (CO_2), in the proportion of 56 parts by weight of lime to 44 parts of carbonic acid. The metal calcium is more costly than gold, not from its scarcity or intrinsic worth, but from the expense of separating it and keeping it separated from its compounds. The metal calcium is quoted in the markets at $10 per grain, yet when combined with oxygen in the form known as quicklime or lime it sells for 50 cents to $1.50 per barrel, while as the carbonate or common limestone ($CaCO_3$) its value is but a slight advance over the cost of quarrying it. Lime occurs in nature in other forms, as the sulphate and phosphate, which, though common, are not nearly so abundant as the carbonate. The most common of the impurities occurring in limestones are magnesia, bitumen, silica, iron, and clay. Calc-spar and aragonite crystals and white marble are practically pure forms.

The common field tests for limestone are that it can be

scratched easily with the point of a knife and will effervesce or bubble when touched with an acid. These are not infallible tests, as other less common rocks will answer the same tests, while on the other hand some highly siliceous limestones are not easily scratched with a knife and a dolomite or limestone containing much magnesia will not effervesce readily with a cold acid.

Mineralogical composition.—Limestone consists essentially of one or more of three minerals: calcite, aragonite, and dolomite.

Calcite is not only the most common and abundant of these three, but it is the most common of all minerals. Dr. Tschermak says:* "The history of calcite is the history of mineralogy." The same author states that the discovery of the principles of crystallography and of double refraction are linked to the varieties of crystallized calc-spar. It belongs crystallographically to the rhombohedral division of the hexagonal system.

Dr. George H. Williams says† it exhibits a greater variety of forms than any other rhombohedral substance; while Dr. Tschermak places it first in this respect in the mineral kingdom.

In 1850 Zippe gave the number of known combinations of crystals as about 700, of which about 136 were simple, and which Descloizeaux gives as about 170 in 1874, and Irby, in a critical review in 1878, gives 50 rhombohedrons and 155 scalenohedrons. Dana says a complete list includes between 150 and 200 forms, with many more that are doubtful.‡ They are from obtuse to acute rhombohedral; from thin tabular to long prismatic; scalenohedral of many types, sometimes of wonderful complexity; twinning very common; fibrous, both coarse and fine; sometimes lamellar, often granular; coarse to impalpable; compact to earthy; stalactitic, tuberose, nodular, and other imitative forms. Some of the best known forms are Iceland spar, or doubly-refracting spar (Doppelspath), a trans-

*Lehrbuch der Mineralogie, p. 430.

†Elements of Crystallography, p. 130.

‡For literature on the subject, see System of Mineralogy, Dana, 6th Ed., N. Y., 1892.

parent variety which shows double refraction; dog-tooth spar, an acute scalenohedron; nail-head spar, a composite variety; and satin-spar (Faserkalk, Atlasspath), a fibrous variety with a silky lustre.*

It is composed essentially of calcium carbonate ($CaCO_3$), but small quantities of magnesium, iron, manganese, zinc, or lead may replace part of the calcium. The hardness varies; earthy varieties as chalk as low as 1, and crystals 3, but the latter varies with the direction on the cleavage face. The specific gravity varies from 2.508 to 2.778, pure crystals from 2.7213 to 2.7234 (Dana). The fracture is conchoidal, but is obtained in crystals with difficulty, owing to its easy cleavage. It is white, colorless, gray, red, green, blue, violet, yellow, brown, or black. Plumbocalcite is calcite with an admixture of lead carbonate ($PbCO_3$). Manganocalcite, spartait, or calcomangite, is calcite with manganese carbonate ($MnCO_3$). Barytocalcite or neotyp, specific gravity 3.46, is calcite with barium carbonate ($BaCO_3$). Strontianocalcite is calcite with strontium carbonate ($SrCO_3$). Zincocalcite is calcite with zinc carbonate ($ZnCO_3$). Ferrocalcite is calcite with ferrous carbonate ($FeCO_3$)

Aragonite named from Aragon, Spain, where it was first discovered, belongs to the orthorhombic system. It crystallizes in simple or compound crystals, the latter being most common, often in radiating acicular crystals and characterized by the presence of acute domes or pyramids. It has also globular, reniform and coralloidal shapes, is sometimes columnar, composed of straight or divergent fibres, and sometimes stalactitic and incrusting. Its composition is the same as calcite, $CaCO_3$. Some varieties contain a little strontium, lead, or rarely zinc. It has a hardness of 3.5 to 4 and a specific gravity of 2.93 to 2.95 The fracture is subconchoidal; the color white, gray, yellow, green, or violet. It is distinguished from calcite by its crystalline form, greater hardness, and greater specific gravity.

Dolomite† (bitter spar, Bitterspath) belongs crystallographic-

*The satin-spar composed of gypsum or sulphate of lime is distinguished from this in being softer and not effervescing with acids. The aragonite satin-spar is harder and heavier.

†Named from Dolomieu, a French mineralogist and geologist (1750–1801).

ally to the rhombohedral tetartohedral division of the hexagonal system. The crystal faces are often curved, and twinning is common. It also occurs columnar, granular, and amorphous. In composition it differs from the two preceding forms, being a double carbonate of magnesia and lime ($CaCO_3$, $MgCO_3$). In normal or true dolomite the molecular ratio is 1 to 1, which equals by weight 54.35 parts of lime carbonate to 45.65 parts of magnesia carbonate, or lime 30.5 per cent., magnesia 21.7 per cent., and carbon dioxide 47.8 per cent. It sometimes contains iron, manganese, cobalt, or zinc carbonate. The ferriferous dolomite, brown spar in part, graduates into ankerite as the proportion of iron increases. The specific gravity for true dolomite is 2.8 to 2.9; hardness 3.5 to 4. The color may be white, reddish or greenish white, rose-red, green, brown, gray, or black.

It may generally be distinguished from calcite and aragonite by not effervescing in a cold acid; but it sometimes requires a chemical analysis for its determination.

THE ORIGIN OF LIMESTONE.*

Chemical origin of limestones.—Water in its passage through rocks containing limestone frequently becomes charged with carbonic acid gas and lime bicarbonate in solution. As it issues in caves or as springs on the surface it is freed from pressure and as some of the gas escapes, lime carbonate is deposited; if in caves it is called stalactite, stalagmite, or pilasters; if around springs or along streams it is called travertine, calcareous sinter, or tufa. The deposit of the lime is due in part to the escape of the gas and in part to the evaporation of some of the water.† Generally the limestone formed in this way is

*Some of the older geologists thought some limestones were of igneous origin. For discussion of this view see Natural History of New York, Part IV, by E. Emmons, 1842, pp. 37–67 inclusive; and Bulletin de la Société Géologique de France, 1882–3, 1st Series, Vol. 3, pp. 215 and 235.

†Water containing lime in solution is known as hard water. If the lime is all in the form of bicarbonate, strange as it may appear, the water may be softened by adding lime water in the proper proportion, the explanation being that lime hydroxide (Ca2HO) in the lime water combines with the excess of carbonic acid in the

in comparatively small quantities. However, in some instances, it forms beds of considerable extent. Thus on a branch of the Tiber near Rome is a heavy bed of travertine from which large quantities of building stone have been taken, St. Peter's and many of the public buildings of Rome being built of it. There are also extensive deposits of travertine about the Hot Springs in Yellowstone Park and elsewhere. Such deposits, however, are of but little importance when compared with the great beds of marine origin.

Some writers contend that similar depositions of limestone, due to chemical precipitation, occur in the sea, the deposit being either from the bicarbonate in solution or by the reaction of alkaline carbonates with the chloride or other salts of lime. One of the strongest advocates of this theory among American geologists is the late Dr. T. Sterry Hunt, who has written numerous papers on the subject. In one place he says: "It is also shown that great portions of limestone, even in fossiliferous formations, have the characters of precipitates resulting from chemical reactions, and have never formed a part of organic beings."* In another place (p. 311) he says: "So many limestones are made up of calcareous organic remains, that a notion exists among many writers on geology that all limestones are, in some way, of organic origin * * * while, independently of the existence of coral and mollusks, the carbonate of lime would still be generated by chemical reactions, and would accumulate in the waters until, these being saturated, its excess would be deposited as gypsum or rock salt are deposited." M. Cordier expresses the same opinion,† holding that both magnesian and calcareous limestones are formed by chemical precipitation in the sea by the action of alkaline carbonates on calcium and

water, and the lime carbonate being insoluble is deposited, the reaction being $CaCO_3$, CO_2 (lime bicarbonate soluble) + CaH_2O_2 (lime hydroxide in the lime water) = $2CaCO_3$ (insoluble) + H_2O (water). The same result is partly obtained by boiling, which sets some of the CO_2 free, and it escapes as a gas. If the hardness of the water is due to the sulphate of lime ($CaSO_4$) in solution, as is frequently the case, lime water will not precipitate the lime.

*Chem. and Geol. Essays, 4th ed., N. Y., 1891, p. 82.

†Comptes Rendus de l'Académie des Sciences, Paris, 1862, Tome 54, pp. 293–299.

magnesium chlorides. M. Leymerie expressed the same views by letter before the French Academy in 1862.*

Prof. Merrill says: "It is very probable that few of our limestones were wholly derived directly from organic remains, but are in part at least chemical deposits. The alternation of beds of snow-white, blue-gray, greenish and almost black layers, as in the Vermont quarries may perhaps be best explained on the assumption that the white layers resulted as deposits from solution, while the darker layers are but beds of indurated shell mud and sand colored by the organic impurities they contained at the time they were first laid down."†

Lapparent says there is a number of marine limestones more or less pure where the source of the carbonate of lime ought to be sought in a chemical precipitation, occasioned by the mutual reaction of salts contained in the water of the sea.‡

In many of the fossiliferous limestones certain portions are apparently deposited from solution, but such deposition at the present time is due to the organic remains, which are sometimes dissolved by the acidulated sea water; this produces a local saturation from which lime is deposited when in contact with the organic fragments.

So far as is known the sea is nowhere saturated with lime carbonate. On the other hand it dissolves the lime brought to it in suspension by streams. Bischof says|| that sea water must be evaporated about 75 per cent. before it deposits lime carbonate, but when it is evaporated about 37.5 per cent. the separation of lime sulphate begins. Hence, if the limestones

*"Or on y parvient d'un manière satisfaisante si l'on admet que les anciennes mers (paléozoiques) n' étaient pas salées de la meme manière que le sont les mers actuelles. Se le sel dominant, au lieu d'etre du chlorure de sodium comme dans l'état actuel des choses, consistait en chlorure de calcium, et qu'on suppose, dans une masse liquide ainsi salée, l'arrivée d'eaux contenant du carbonate de soude, il en résulterait une double décomposition, et par suite un précipité de carbonate de chaux et la formation de chlorure de sodium." Lettre de M. Leymerie à M. d'Archaic, Comptes Rendus de l'Académie des Sciences, 1862, Tome 54, p. 567.

†Stones for Building and Decoration, by G. P. Merrill, N. Y., 1891, p. 79.

‡Traité de Géologie, p. 685.

||Chem. and Phys. Geol., Eng. ed., Vol. I., p. 117.

had precipitated from sea water by evaporation they should contain more sulphate than carbonate, which is not the case. Nor does any good reason present itself for considering the sea at former times to be any nearer saturation than at present, except in isolated or enclosed areas. But even assuming such to be the case, a saturated mother liquor should have been left.

Prof. William Dittmar, who has probably made more extended researches in this line than any one else, quotes Dumas' remark to the effect, that when the amount of carbonic acid in the sea water decreases, bicarbonate of lime is broken up and the neutral lime carbonate is precipitated; he then adds that he disagrees with him and concludes from his own experience that the sea water, even when it contains its minimum of carbonic acid, is not saturated with the carbonate of lime, but is ready to dissolve what is brought in by the rivers.*

When we furthermore take into account that some, perhaps a large part, of the lime that appears to be a chemical precipitate in the fossiliferous limestone has been so deposited by infiltrating waters, subsequent to the original formation of the rock, it appears even less probable that any considerable part of marine limestones has been formed by chemical precipitation.

Organic origin of limestones.—As nearly all limestones are directly or indirectly produced through the agency of some form of animal or vegetable life, this phase of the subject will be treated somewhat more in detail.

Kinds of organisms that produce limestone.—Both animal and vegetable organisms secrete limestone, but the first in much larger quantities. While the bony skeleton of vertebrates consists in part of lime, the quantity of limestone resulting from their remains is small compared with that produced by the invertebrates. The researches of Sorby also show that the skeletal remains of these various organisms vary consider-

*Report of Challenger Expedition; Phys. and Chem. by William Dittmar, Vol. I., p. 221.

ably in mineralogical composition,* some being composed of calcite, others of aragonite, and some of both these minerals.

More recent experiments by Cornish and Kendall† go to show that aragonitic shells are much less durable than the calcitic ones. They lose from two to three times as great a percentage of weight in carbonated water as calcite, and after losing 60 per cent. they fall into fragments, while calcite shells remain firm until entirely dissolved. They carried their experiments further and showed that this variation was due to the difference in texture of the aragonite and calcite shells, as the powdered crystals or even the finely powdered fossil shells, of the two minerals showed but slight difference in durability.

Foraminifera.—One of the most important groups of lime-producing animals is the foraminifera, a group of microscopic protozoa including *Globigerina*, *Orbitoides*, *Nummulina*, *Saccammina*, *Rotalia* and other genera. So far as is known the tests of foraminifera do not constitute a prominent part of any pre-Carboniferous beds. But from the beginning of the Carboniferous period to the present time they have produced large quantities of limestone; at the present time the deposits formed from their remains far exceed in quantity those from all other organisms combined. They may be divided into two large groups, one comprising all the species which live on the floor of the ocean and the other comprising those which live in the surface and subsurface waters of the open sea.

There are not more than twenty or twenty-two species of pelagic, surface-living foraminifera, yet so numerous are the individuals that they usually make up over 90 per cent. of the carbonate of lime in the calcareous oozes of the deep sea. This is true also in regard to their great development in Tertiary and other geological formations.

The bottom-living foraminifera are more abundant in the shallow water than in the deep-sea deposits, occasionally a single species occurring in such abundance in some regions as to make up the greater part of a deposit, but the extent of

*Quar. Jour. Geol. Soc., 1879, pp. 56 *et seq.*

†Geological Magazine, February, 1888, Decade III., Vol. V., No. 2.

such deposits is limited when compared with that of the other deep-sea deposits.

Sorby shows that the skeletons of foraminifera are mostly of calcite, but that aragonite and phosphate of lime are sometimes present; Cornish and Kendall found that one family, the Porcellana, has skeletons of aragonite.

Corals (*Madreporaria*).—Corals are the principal, though not the only lime producers among the Cœlenterate animals. Many limestones from the oldest Paleozoic times to the present are composed wholly or in large part of corals.

While corals are the chief lime producers among Cœlenterate animals, certain hydrozoa are capable of forming extensive deposits of lime. The Hydrocoralline genus *Millepora* is the only one of the hydrozoa known to play an important role in limestone building at the present day. The hard parts are mainly calcite.

Echinoderms.—By far the most important order of echinoderms as lime builders are the crinoids ("sea lilies" or "stone lilies)". In deposits of Silurian, Devonian, and Carboniferous ages, especially the Lower Carboniferous, are extensive beds of limestone made up almost wholly of crinoid fragments, and known as crinoidal or encrinital limestones or marbles. Crinoids, however, are not abundant in existing seas. The skeletons are of calcite.

Crustaceans.—Among crustaceans the most important as lime producers are the trilobites and ostracods, of which the former are now extinct. Great numbers of other crustaceans, such as crabs, lobsters, etc., which secrete skeletons of carbonate of lime (mostly calcite), live in the sea, but their remains, owing to their rapid disintegration, are rarely found in marine deposits.

Bryozoans.—While the polyzoa or bryozoa form a conspicuous part in many Paleozoic limestones, they occur in larger quantities in some of the Mesozoic and Tertiary beds. They occur in great numbers in existing seas. Their hard parts consist of calcite and aragonite, according to Sorby.

Brachiopods.—The Brachiopoda were most numerous in

Paleozoic times. Many of the Silurian, Devonian, and Carboniferous limestones are largely made up of brachiopod shells. They seem to have reached their maximum development in Devonian times.* While they live in existing seas they are not common and not prominent among the lime-forming animals.

Lamellibranchs.—The Lamellibranchiata occur in great abundance in limestone beds from the earliest Paleozoic times. The oysters, pectens, and other well-known forms occur in vast numbers at the present time. Some of the shells, as oysters and pectens, are entirely of calcite, but many are wholly of aragonite, while others have an inner layer of aragonite and an outer one of calcite.

Gasteropods.—The Gasteropoda, though less abundant than the lamellibranchs, have aided in limestone building from early Paleozoic time to the present and are now on the increase. The shells are mostly aragonite, but some species have an outer layer of calcite.

Cephalopods.—Cephalopod shells occur in limestone of all ages from the early Paleozoic; the animals are now decreasing in numbers. Their shells are aragonite.

Pteropods and Heteropods.—The Pteropoda and Heteropoda are mollusks that live in the surface and subsurface waters of the open sea, being especially abundant in tropical waters. Both occur fossil in Paleozoic and more recent limestones. The Tentaculites† form beds of Devonian age in the Hartz Mountains, and of the Upper Silurian age in New York. Prof. Dana says the Tentaculites reached their climax in Upper Silurian times.‡

Fishes.—So far as is known, the skeletons of fishes form no considerable part of any limestone deposits, except the otoliths and teeth, which occur in considerable number in some of the calcareous oozes.

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*Text-Book of Geology by Sir Archibald Geikie, p. 697.

†The Tentaculites are commonly believed to be pteropods but are by some writers classed as annelids.

‡James D. Dana, Manual of Geology, p. 253.

Algæ.—Species of calcareous algæ are abundant in the shallow waters of the ocean, especially in tropical regions, where they form a considerable part of some coral reefs and the surrounding coral mud and sand. The most abundant are the Corallines. The coccospheres and rhabdospheres, so abundant in the calcareous oozes of the deep sea, are supposed to be pelagic algæ. Some forms of algæ are found fossil, and form a considerable part of some beds of Triassic age in the Alps.

DEEP-SEA DEPOSITS.

Dredgings and soundings made in all parts of the ocean show that the ocean's bottom the world over is covered with a soft mud, commonly known as ooze. This ooze is made up largely and in many cases entirely of the skeletons of animals too small to be seen without the aid of a microscope. These skeletons are of various organisms and the oozes have been named according to the predominating types: Radiolarian ooze, Diatom ooze, Globigerina ooze, Pteropod ooze. Other of the deep-sea deposits are called Red clay, Red mud, Blue mud, Green mud, Coral mud, etc., according to the nature of the material. These clays, muds, and oozes are characteristic deep-sea deposits now being formed; they all contain carbonate of lime, most of them in sufficient quantity to class them as limestones, and some of them as comparatively pure ones. They have an interesting relation to the continental limestones, and some of the chalk beds are supposed to be identical in origin with certain deep-sea deposits. The chalk deposits of the Barbadoes are composed of calcareous shells such as might now be found in Atlantic ooze at a depth of 1000 fathoms. "There can be no doubt that these chalky earths and limestones were formed in the same manner and at the same depths as the chalky muds which are now being formed in many parts of the Atlantic and Pacific Oceans."*

Prof. J. W. Bailey states that a microscopical examination

*The Geology of Barbadoes, by J. B. Harrison and A. J. Jukes-Browne, 1890, p. 17. See also Trans. Edinb. Geol. Soc., Vol. VI., p. 56, 1890; Ann. and Mag. Nat. Hist., Ser. VI., Vol. VI., p. 45, 1890.

of the soundings made by the United States Coast Survey along the Atlantic Coast from Montauk Point to Cape Henlopen shows vast amounts of foraminifera, rivalling in abundance the deposits of analogous species which he found to compose immense beds under the City of Charleston, S. C.*

After making a study of English chalk, Sorby says in substance† that though it contains many foraminifera it contains also a large proportion of other larger calcareous organisms. He concludes that chalk is not identical with Globigerina ooze, and is equally unlike any of the older rocks, but that it is analogous to deep ocean mud, to which has been added much detritus derived from larger shells. Murray says‡ that, with some exceptions, no continental rocks have been recognized as identical with the deep-sea deposits. Subsequent study of the continental rocks in the light of what is now known of the deposits of the deep sea will probably show many of them to be deep-water deposits.||

The Red clay.—The Red clay covers the deeper parts of the ocean, and is the most extensive of all marine deposits, occupying an area equal to more than one fourth the surface of the globe. The carbonate of lime found in it consists principally of the remains of calcareous organisms that live in the surface waters, but so far as its lime contents are concerned the Red clay is the least important of the deep-sea deposits, and, as shown below, the percentage of lime decreases as the depth increases.

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*Smith. Contrib. to Knowl., Vol. II., Art. 3.

†Quar. Jour. Geol. Soc., Vol. XVIII., p. 78.

‡Challenger Reports, Deep-Sea Deposits, p. 189.

||The most complete and exhaustive treatise on this subject is the report on Deep-Sea Deposits by Murray and Dittmar, which forms one volume of the reports on the Challenger Expedition. The following remarks give a brief outline of the most important features of that report bearing directly on the deposit of lime carbonate. The deep sea in this chapter signifies a depth of more than 100 fathoms (600 feet).

Relation of carbonate of lime ($CaCO_3$) *to depth of the deposit.*

Depth in fathoms.	Percentage of lime carbonate.
2,000 to 2,500	8.39
2,500 to 3,000	7.16
3,000 to 3,500	0.88

Radiolarian ooze..—The Radiolarian ooze, like the Red clay, is confined to the deeper parts of the ocean. It differs from the red clay only in the greater number of radiolarian remains, together with sponge spicules and diatoms. The carbonate of lime in nine samples ranges from a trace to 20 per cent., the average being 4.01 per cent. Of the whole deposit, 54.44 per cent. consists of siliceous organisms. The entire area covered by the Radiolarian ooze is about 2,290,000 square miles.

Diatom ooze.—The Diatom ooze is composed largely of diatom skeletons, and the carbonate of lime in it varies from 2 per cent. to 36.34 per cent., the average being 22.96 per cent. 41 per cent. of the whole deposit consists of siliceous organisms. The Diatom ooze is confined to the polar regions, the total area covered being 10,970,000 square miles.

Globigerina ooze. — Murray limits the term Globigerina ooze to deposits which contain "over 30 per cent. of carbonate of lime, principally made up of the dead shells of these Foraminifera." He says: "Were all the deposits which contain 10 or 15 per cent. of these foraminiferous shells classed as Globigerina ooze then this deposit would be by far the most extensive of the deep-sea deposits. The color of the deposit is white, milky-yellow, rose, brown, or grayish, depending on the nature of the inorganic substances mixed up with the Foraminifera. The prevailing color is milky-white, or rose-colored far from land, and dirty white, blue, or gray near land, when there is a considerable quantity of detrital matter from rivers in the deposit. It has sometimes a mottled aspect from the presence of manganese grains of volcanic ashes, lapilli, and fragments of pumice. It is fine-grained and homogeneous; in tropical regions many of the Foraminifera are visible to the naked eye, while in temperate regions the form

of the organisms is, as a rule, indistinguishable without the aid of a lens. When dried a Globigerina ooze is usually pulverulent, but some specimens which have a low percentage of carbonate of lime cohere slightly."*

The carbonate of lime in the Globigerina ooze ranges from 30.15 per cent. to 96.8 per cent., the average being 64.47 per cent.

The percentage of carbonate of lime decreases with the increase of depth, as shown below, a fact which would be more strikingly exhibited, Mr. Murray says, if the samples had all been from one region of the ocean, in which the surface conditions were the same.

Carbonate of lime in deposits of Globigerina ooze at different depths.

No of samples.	Depth in fathoms.	Percentage of lime carbonate.
33	Under 500	87.07
2	From 500 to 1000	68.47
13	From 1000 to 1500	63.69
35	From 1500 to 2000	72.66
49	From 2000 to 2500	61.74
16	Over 2500	49.58

The area covered by Globigerina ooze is estimated at 49,520,000 square miles, next in size to the Red clay area.

Pteropod ooze.—Pteropod ooze is the term used to designate the deep-sea deposit in which a large part of the calcareous organisms consists of shells of Pteropods and Heteropods, along with those of other deep-sea and bottom-living mollusks. It differs from a Globigerina ooze, which it closely resembles, by the presence of a larger percentage of lime carbonate, due to the greater abundance of these shells. These pelagic mollusks are abundant everywhere in the surface waters of the tropical and subtropical oceans, yet their remains are wholly absent from all the deposits in the deepest waters. A few traces of them were found as deep as 2000 fathoms, but it is only in shallower depths, 500 to 1500 fathoms, that they make up any considerable part of the deposit. Analyses of thirteen

*Challenger Report, Deep-Sea Deposits, p. 214.

samples show the carbonate of lime to vary from 52.22 per cent. to 98.47 per cent., with an average of 79.25 per cent. The Pteropod ooze was found to cover an area of about 400,000 square miles in the Atlantic Ocean.

OFF-SHORE DEEP-SEA DEPOSITS.*

Those already described are pelagic or deep-sea deposits properly speaking, and are formed in deep water removed from the land. There are other deposits formed in deep waters (over 100 fathoms) close to the land masses, and mostly made up of materials derived immediately from the land. These are called Blue mud, Red mud, Green mud, Volcanic mud, and Coral mud.

Blue Mud.—Blue mud is the name given to blue or slate-colored deposits frequently found in the deeper waters surrounding continental land, and in all enclosed or partially enclosed seas more or less cut off from free communication with the open ocean. The carbonate of lime in the Blue mud varies from a trace to 34.34 per cent., the average being 12.48 per cent. The quantity does not decrease regularly with the increase in depth, but is subject to many local variations. The Blue mud deposits are estimated to cover an area of 14,500,000 square miles, the largest area occupied by deposits derived from the land.

Red mud.—The Red mud occurs along the coast of Brazil and in the Yellow Sea off the coast of China. Its red-brown color is due, apparently, to the ochreous matter brought down by the rivers. The carbonate of lime ranges from 5.75 to 60.79 per cent., the average being 32.28 per cent. The area covered by the Red mud is estimated at 100,000 square miles.

Green muds and sands.—The Green muds differ from the Red and Blue muds, which they resemble in many respects, by the glauconitic grains and casts of calcareous organisms which they contain. The carbonate of lime ranges from a mere trace to 56.18 per cent., the average being 25.52 per cent.

*Designated terriginous deposits by Murray in Challenger Report, Deep-Sea Deposits.

in the Green mud and 49.78 per cent. in the Green sand. The Green muds and sands appear to form an interrupted band along many continental shores at the upper edge of the continental slope, the estimated area being 1,000,000 square miles, including those in the shallow-water zones.

Volcanic muds and sands.—The Volcanic muds and sands are composed of debris from the disintegration of volcanic rocks and are found along coasts where volcanic rocks prevail, being especially prominent around volcanic islands. The carbonate of lime ranges from a trace to 71.65 per cent., the average being 24.49 for the muds, and 28.79 for the sands. The area estimated to be covered by the Volcanic muds and sands is 750,000 square miles, which includes the area of the volcanic islands themselves.

Coral muds and sands.—The Coral muds and sands are the deposits formed around coral islands and reefs and consist largely of fragments of coral, algæ, mollusks, and other organisms. In the shallower waters these fragments form a coarse sand or gravel, but in the deeper waters they form a fine mud consisting largely of triturated particles of organic remains, and merging gradually into the Pteropod ooze or Globigerina ooze, with no marked line between the two. They are of various shades of white, the residue, after dissolving the lime, being of a brown or reddish color. The residue consists of oxides of iron and mineral particles with a few siliceous organisms. This deposit is largely composed of carbonate of lime, which ranges from 77.38 per cent. to 89.68 per cent., the average being 85.53 per cent. and 86.84 per cent. The area covered by the Coral muds and sands is estimated at 2,700,000 square miles.

Percentage of carbonate of lime in the different deep-sea deposits, and the form in which it occurs.

Off-shore deposits.	Pelagic foramini-fera.*	Bottom-living for-aminifera.	Other organ-isms.	Total per cent.
Coral mud	31.27	14.64	39.62	85.53
Coral sand	36.25	20.00	30.59	86.84
Volcanic mud	10.50	2.82	7.17	20.49
Volcanic sand	13.00	13.80	11.99	28.79
Green mud	14.59	2.94	7.99	25.52
Green sand	21.00	15.00	13.78	49.78
Red mud	13.44	3.33	15.51	32.28
Blue mud	7.52	1.75	3.21	12.48
Deep-sea deposits.				
Pteropod ooze	47.15	3.15	28.95	79.25
Globigerina ooze	53.10	2.13	9.24	64.47
Diatom ooze	18.21	1.60	3.15	22.96
Radiolarian ooze	3.11	0.11	0.79	4.01
Red clay	4.77	0.59	1.34	6.70

Summary.—The researches of the Challenger expedition show: (1) That lime-secreting organisms are most abundant in tropical regions and least so in the polar regions. (2) That the remains of pelagic or surface-living foraminifera, mollusca, and algæ far exceed the coral deposits. (3) That the calcareous remains decrease with the increase of the depth, despite the fact that the members living on the surface may be as numerous in deep waters as in shallow. The scarcity in the greater depths is due to the fact that they have been longer subject to the solvent action of sea water, caused by the longer passage to the bottom, the greater pressure, and to the fact that they are not covered so rapidly. Hence, the more delicate and porous shells are the first to disappear. (4) The calcareous shells disappear at lesser depths in temperate and polar regions than in tropical regions.

THE ACCUMULATION OF ORGANIC REMAINS OTHER THAN DEEP-SEA DEPOSITS.

The way in which the remains of organisms which secrete calcareous skeletons accumulate and the kind of limestones thus formed is described by Prof. James D. Dana as follows:

*Those living in the surface and subsurface waters.

"Coral reefs are beds of limestone made of corals, with the help of shells and other calcareous relics of the life of the sea. The mode of formation is essentially the same whichever of the two kinds of organic products—corals or shells—predominate.

"The reefs illustrate two different modes of origin of such beds: (1) By undisturbed growth, with only additions of fine material to fill up the intervals; (2) by the grinding of corals etc., to fragments, sand, or mud, through the agency of the waves.

"* * * In accordance with these facts (storm waves and parasitical action) the reef formations illustrate that not only coral conglomerates, or *coral rag*, may be made of corals, but also the very finest and most compact unfossiliferous limestones; that fine compact limestone, as flint-like in fracture as any of Silurian time, is one of the most common of coral-reef rocks, and is nothing but consolidated mud, or fine sand, of coral origin.

"Besides the kinds of coral rocks above mentioned, there are also the *Beach* and *Drift Sand-rocks*, which are accumulated and consolidated above low-tide level. These formations illustrate the common mode of origin of oölitic limestones. They also afford numerous examples of the formation of coarse and fine conglomerates consisting of beach pebbles—these pebbles being either worn corals, or shells, or sometimes of other kinds, if other rocks are at hand.

"The general slope of the beach sand-rock and oölite, and the mixed stratification of the drift sand-rocks, are identical respectively with those of beach and drift-sand deposits in other regions.

"The coral reef rock has been shown to have in some cases a thickness of at least 2000 feet. The reefs are, therefore, examples of great limestone strata, nearly as remarkable in this respect as the largest of ancient times."*

The littoral deposits are subject to greater variation in composition and structure than those of the deeper sea. They are

*Corals and Coral Islands by James D. Dana, 3d ed., pp. 385 *et seq.*

constantly subject to the tides and currents and periodically to storms and to variations in the quantity of sediments brought in by the streams. They are dependent in great measure on the character of the rock forming the coast and even to the contour of the coast line. Thus for a few years the conditions may be favorable in a certain place for the growth of the oyster or some other prolific mollusk whose remains will accumulate in a great bed when the washing away of some promontory or cutting through of some peninsula will change the currents and the deposition of sediments, and the deposits of lime shells will be covered with sand or clay. The shell deposits formed in comparatively still water in a sheltered bayou or on a quiet beach will show their organic origin; if formed on a rocky beach subject to storms, the shells will be ground to fragments and mixed with the debris of the rock forming the shore.

THE CONSOLIDATION OF LIMESTONES.

Limestones formed of the remains of calcareous organisms may be consolidated in one of two ways. First, by a submarine process which appears to depend on the presence of carbonic acid in the sea water. That the acid is present is shown by chemical analyses; it is derived partly from the rains, which wash it down from the atmosphere, but chiefly from the respiration and decomposition of organisms and from submarine springs and volcanic eruptions. As shown by the investigations of Murray and others, the acid acting on the fine debris takes some of the lime into solution, and the deposition of this lime among the grains produces the cementation.

The second process of consolidation is one that takes place on the shore, and is not essentially different from the other. The shell fragments and drift sand of the beach receive a coating of lime carbonate from the sea waters with the ebb and flow of the tides. The evaporation of the water between the flow of the tides leaves a thin coating of the lime carbonate on the fragments, which acts as a cement, binding them into a solid mass. It sometimes happens that the particles are not only bound together by this means, but even the particles

themselves are changed to a crystalline condition. The consolidation is sometimes due in part at least to the percolation of meteoric waters.

CIRCULATION OF CARBONATE OF LIME.

The ready solubility of limestone in acidulated waters, the abundance of carbonic acid in the waters, the wide distribution and abundance of limestone in the earth's strata are the conditions favorable for the dissolution of vast quantities of lime carbonate; the countless multitudes of animal and vegetable organisms that secrete it are the agencies that tend to counterbalance this destruction. It would thus appear that through the agency of water, acid, and life, the lime carbonate is in a continuous circuit from stratified rock, through living organisms, to stratified rock again. With the exception of water it probably passes back and forth between the animal and mineral kingdoms in greater quantities than any other compound.

The great quantities in the deep sea have been spoken of, and it is not less abundant in littoral deposits than in those of the deep sea, though its local variations are greater in the littoral deposits. It now remains to speak of the destruction of the limestone beds that occur over the land surfaces, and to show the source of supply of the lime for the organisms which secrete it.

Some of the limestone is carried into the rivers and sea in suspension as sediment, like sandstone, shale, and other rocks, but owing to the abundance of free carbonic acid in the water, large quantities of it are dissolved and held in solution instead of being deposited with the mechanical sediments. Furthermore, large quantities are taken in solution by the acidulated waters from the rock *in situ*. Thus in every limestone region the numerous caverns and sink-holes are the results of the removal of vast quantities of limestone that have been carried away in this manner. So universal is this action of acidulated waters on limestone that there are but few streams which do not carry lime in solution, even in places where no limestone

outcrops on the surface, as the water from subterranean sources frequently brings lime from deep-lying beds.*

It has already been mentioned that the free acid in the sea water redissolves some of the lime carbonate.

It is not known how much lime carbonate may be derived from the sulphates, chlorides, and silicates, by chemical action, either directly or indirectly through animal organisms,† but it is known from analyses that a considerable part of the salts of the sea water is made up of sulphates. The action of organic matter on the sulphates is to reduce them to the sulphide with the production of carbonic acid. The carbonic acid acting on the sulphide decomposes it, forming carbonate salts and setting hydrogen sulphide free, which in turn oxidizes to sulphuric acid, which attacks and decomposes the carbonates.‡ It would thus appear that there is a constant interchange of acids with the lime salts in solution.

Mr. J. Y. Buchanan suggested before the British Association in 1881 that the animals of the sea assimilate their lime from the sulphate, forming the sulphide in the interior of the animal, which is transformed into carbonate on the exterior. (Geikie.)

The fertility of many an otherwise barren soil is due to the free circulation of lime carbonate, which through the agencies of vegetation, land mollusks, and other animals, is extracted from the carbonated waters and distributed through the soil, in the organic remains.

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*A. L. Ewing carried on a series of investigations in Limestone Valley, Pennsylvania, to ascertain the amount of lime carried away in solution, and concludes that the total solids in solution are equivalent to not less than 275 tons per square mile per annum, the greater part of which is lime carbonate. Am. Jour. of Sci., 3d Ser., Vol. 29, 1885, p. 29.

The State Geologist carried on for one year a series of observations on the Arkansas River at Little Rock, for the purpose of determining the amount of solid matter removed from the hydrographic basin of that stream. His results show that from October 3, 1887, to October 2, 1888, there were carried out of that basin 6,828,350 tons of matter in solution, of which 18 per cent., or 1,229,103 tons, were carbonate of lime.

†At ordinary temperature carbonic acid replaces silicic acid, thus changing silicates to carbonates without the aid of life. At fusion temperature the process is reversed, the silica replacing the carbonic acid.

‡Murray, Deep-Sea Deposits, p. 255.

Chemical changes which lime as a base undergoes, that is, its changes from one acidulous radical to another, as the change of carbonate to sulphate, thence to sulphide and carbonate again, the change from silicate to carbonate, etc., can only be mentioned as suggestive of the important part which such changes take in the tearing down and upbuilding of the limestone beds.

THE ORIGIN OF DOLOMITE.

As already stated (p. 16) the theoretical composition of the mineral dolomite is 54.35 per cent. by weight of carbonate of lime to 45.65 per cent. of the carbonate of magnesia, but from the fact that limestones occur with the percentage of magnesia carbonate varying all the way from a fraction of 1 per cent. to nearly 45.65 per cent. and that all limestones have accessory substances as impurities, the term is rather loosely used by different writers. Von Cotta* proposes that limestones containing upwards of 23 per cent. of carbonate of magnesia should be classed as dolomites, while Paget† classes as dolomites those rocks containing 18 or 20 per cent. and upwards, and N. H. Winchell‡ limits the term to limestones containing 40 per cent. or more of magnesia carbonate. A much better limitation of the term, however, would be one based on the proportion of the lime carbonate to the magnesia carbonate, since it is possible for a rock containing 30 per cent. of carbonate of magnesia to be more nearly a true dolomite than one containing 35 per cent., if there is a much larger proportion of silica or other impurity.

The origin or formation of dolomite has long been a subject of discussion. The two theories held are (1) that it is a chemical deposit; (2) that it is produced by dolomitization.

Chemical deposit.—One of the strongest advocates of the chemical deposit theory is the late Dr. T. Sterry Hunt; he divides the dolomites into two classes: those associated with gypsum, and those which are not so associated. The first he

*Rocks Classified, p. 245.

†Advanced Text Book of Geology, p. 102.

‡Geology of Minnesota, Vol. I., p. 253.

says are produced by the decomposition of magnesia sulphate by bicarbonate of lime, while the second are produced by the decomposition of chloride or sulphate of magnesia by alkaline carbonates. In both cases, however, the bicarbonate of magnesia aids in forming a considerable part of the sediment.* In another place (Essays, p. 90) he says that dolomites, magnesites, and magnesian marls have their origin in sediments of magnesian carbonate formed by the evaporation of solutions of bicarbonate of magnesia. Ramsay,† Cordier, and Leymerie‡ express similar views.

Dr. Irving|| says that calcium being more strongly electro-positive than magnesium would replace the latter in haloid salts, thus:

$$CaCO_3 + MgCl_2 = CaCl_2 + MgCO_3.$$

and that the calcium chloride would be removed in solution, and the carbonate of magnesia be deposited. These things happening together and magnesia readily forming double salts, dolomite might, at a later stage, readily have been produced directly by chemical reactions. In the same place he states that dolomite may be produced by the direct action of sea water upon a deposit of pure carbonate of lime.

Dolomitization.—Probably the majority of leading geologists of the present day consider that some of the dolomites at least are formed from common limestones by a process known as dolomitization, by which the proportion of magnesia has been increased since the deposition of the limestone. Bischof,§ after summarizing all the views of his time, reaches the following conclusion: "Taking into consideration all the facts known with regard to dolomite, as far as it occurs as a rock mass, it can only be regarded as a product of the alteration of limestone in the wet way; and there is no mode of alteration

*Chemical and Geological Essays, p. 309. Dr. Hunt advocates similar views in numerous other papers.

†Quar. Jour, Geol. Soc., 1871, pp. 248–9.

‡Compt. Rend. Acad. des Sci., Tome 54, 1862, p. 294 and p. 568.

||Metamorphism of Rocks, Dr. A. Irving, p. 8.

§Chem. and Phys. Geol., Eng. ed., 1859, Vol. III., pp. 155 to 203.

that is more probable than the substitution of carbonate of magnesia present in water for a portion of the carbonate of lime in limestone, or the extraction of the greater part of carbonate of lime by the water permeating the limestone."

Geikie says:* "Some dolomite appears to be an original chemical precipitate from the saline water of inland lakes and seas. But calcareous formations due to organic secretions are often weakly dolomitic at the time of their formation, and may have their proportion of magnesium carbonate increased by the action of permeating water, as is proved by the conversion into dolomite of shells and other organisms, consisting originally of calcite or aragonite and forming portions of what was no doubt originally a limestone, though now a continuous mass of dolomite. This change may have sometimes consisted in the mere abstraction of carbonate of lime from a limestone already containing carbonate of magnesia, so as to leave the rock in the form of dolomite; or probably more usually in the action of the magnesium salts of sea water, especially the chloride, upon organically formed limestone; or sometimes locally in the action of a solution of carbonate of magnesia in carbonated water upon limestone, either magnesian or non-magnesian." Newberry says:† "Dolomite, like limestone, is an organic sediment; sometimes an original deposit, sometimes the result of a somatic chemical change. The arguments in favor of this view are, as it seems to me, conclusive, as we have fossiliferous limestones containing all quantities of magnesia from 1 per cent. up to 44. As to the source of the magnesia we have yet much to learn. Prof. Benjamin Silliman has shown that some corals, and especially Millepores contain magnesia up to 18 per cent., but the foraminifera have doubtless contributed more to the formation of most limestones than any other organism. The chemical theory of the formation of dolomite advocated by Hunt and others, seems to me entirely theoretical and improbable."

Interesting examples in the Carboniferous limestone in Kil-

*Text-Book of Geology, p. 296.

†Communicated to the writer, December, 1890.

kenny are recorded by the Irish geologists, where the change from shelly limestone into true dolomite is quite striking.

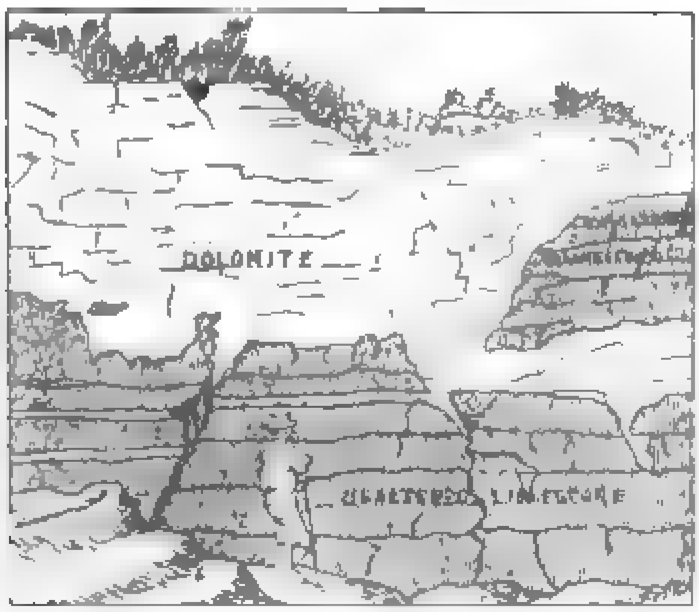

FIG. 1.—*Vertical section of limestone quarry at Kilkenny, Ireland, showing dolomitization (after Prestwich).*

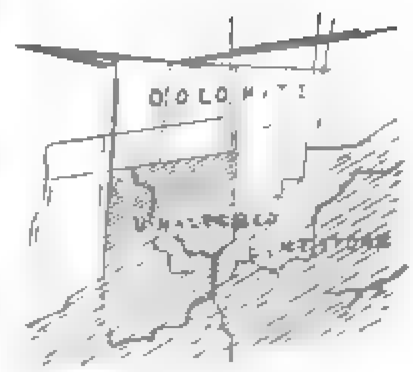

FIG. 2.—*Horizontal section of limestone quarry at Kilkenny, Ireland.*

Fig. 1 *shows a section in a limestone quarry in Ireland illustrating the change from common shelly limestone to gritty dolomite with fossils and stratification obscured or destroyed, the transition from one to the other being abrupt, irregular, and independent of the bedding. The alteration, however, proceeds along the lines of joints, against which it frequently stops, as shown in the ground plan in Fig. 2. From this and similar examples given by the Irish geologists it would seem that at least some of the magnesian limestones are caused by somatic changes subsequent to deposition. In middle Germany in the Muschelkalk, middle Trias, the Trochitenkalk is often dolomitized along fault lines, the dolomitization extending only a few feet on each side of the fault. The same thing occurs in the Coral-rag of the upper Jurassic, where, extending over miles of country, is a massive, unstratified, and almost unfossiliferous dolomite, while a few miles away the same strata occur as a soft oōlite rich in fossils. Many German geologists associate the dolomitization with the disturbance of the strata.

*A. Wyley, Journal of Geological Society of Dublin, Vol. VII., pp. 115, 122. Quoted in Prestwich Geol., Chem. Phys. and Strat., Vol. I., p. 113.

Sorby,* speaking of the magnesian limestones of England, says: "That some chemical replacement did occur admits of no doubt; but it might be going further than the evidence warrants to conclude that the whole rock was entirely altered by true replacement, without any direct chemical precipitation of magnesia. I must say that, taking into consideration the microscopical structure of the rock and its other anomalous characters, some such combined organic and chemical origin appears more probable than either alone, though it may be difficult to decide to what extent each was instrumental in producing the main mass of the deposit, on account of the original structure having been so commonly lost."

After the discussion of a long series of investigations on magnesian limestones carried on by the Pennsylvania Geological Survey, Prof. J. P. Lesley, the State Geologist, concludes as follows: "The only generalization I can make from the above data is a negative one, namely: that no theory of percolation can account for the facts; that no theory of more rapid dissolution of carbonate of lime, leaving a growing charge of carbonate of magnesia behind, will apply to rocks which are neither honeycombed, nor visibly porous, nor unusually cleft, nor otherwise disturbed; and that any theory to account for the presence of the magnesia must treat the layers of both species as equally mechanical sediments; especially, seeing that the larger part of the insoluble matter resides in those which contain most magnesia; while magnesia is present in all of both kinds."†

It will be seen from the foregoing that no one explanation of dolomitization answers for all cases. The record of careful observers appears to show conclusively that some dolomites are formed directly by chemical precipitation or sedimentation, while others are undoubtedly formed by a change subsequent to deposition, either by a simple leaching out of some of the

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*Proceedings Geological Society of London, 1878–9, p. 85.

†Report M M, 2d Geological Survey of Pennsylvania, p. 361.

lime carbonate from a magnesian limestone, or by a replacement of some of the lime by magnesia.*

While no organic remains have been found which consist of dolomite, some contain a high percentage of magnesia carbonate. The magnesia in some corals has already been mentioned. The researches of the Challenger expedition show that foraminifera contain from 5 to 26 per cent. of magnesia carbonate. The highest, 26 per cent., was found in a fossil specimen; the highest found in a living species was 12.52 per cent.

*A full statement of the literature upon the subject of magnesian limestones will be found in a memoir by C. Doelter and R. Hoernes. Jahrb. Geol. Reichsanstalt, XXV., Vienna.

CHAPTER III.

Varieties of Limestone.

Some of the various mineral forms of carbonate of lime have been already mentioned. As a rock-making constituent calcite never occurs in crystals*, but in irregularly bounded grains and plates, in parallel or radiating fibrous aggregations, or in the concretionary oōlitic form. The varieties of rock masses composed of limestone are almost innumerable. A strictly scientific classification of the different varieties is not possible, as they are for the most part named for some one property of the rock, hence any one limestone may be known under a great many names. They may be named from their (1) impurities, (2) structure, (3) texture, (4) origin, (5) color, (6) use, (7) locality, (8) geologic age, or (9) appearance; the more common varieties will be described under these heads.

Varieties due to impurities.—Impurities may occur in limestones in a minute state of subdivision, diffused through the rock; in nodular, lenticular, or laminated masses; or in mineral crystals or aggregates. The common impurities found diffused through the rock are magnesia, silica, alumina, iron, manganese, potash, soda, and bitumen. One or more, sometimes all, of these substances occur in a mass of limestone, and if any one becomes prominent it is customary to name the stone from it. The point, however, at which a limestone containing silica, for example, is called siliceous, is purely an arbitrary one, as very few limestones are entirely free from silica. A magnesian limestone, for example, is one containing magnesia, but is not so called unless the magnesia forms 10 per cent. or more of the whole. A siliceous limestone is one having a considerable per cent. of silica; if the silica occurs in the form of

*Rosenbusch, Microscopical Physiography of Rock-making Minerals, English edition, p. 174.

grains of sand it is called arenaceous. An argillaceous limestone is one containing alumina in the form of clay; some of the argillaceous and siliceous limestones, when burnt, form hydraulic lime. Ferruginous limestones contain iron; and manganiferous limestones are those containing manganese. Potash and soda occur only in small quantities. Bituminous limestone contains carbonaceous matter, which gives the stone a dark, sometimes black color, and frequently gives out a fetid odor when rubbed or struck with a hammer; from this latter property it is named anthraconite, stinkstone, or swinestone. If present in large quantities, bitumen injures the stone for building or ornamental purposes by discoloration and by its disagreeable odor; if present in sufficient quantities, it may injure the texture of the stone, but in small quantities it may even be beneficial.

The minerals which occur in limestone are numerous, but most of them do not occur in large quantities. Pyritiferous limestone contains iron pyrites, a substance which in small quantities discolors the stone, and in large quantities injures its texture. If diffused in small crystals the only effect it has is to mellow the stone with age as the pyrite oxidizes. Galena* limestone contains galena or sulphide of lead and is often valuable for its lead contents. Other minerals found in limestone are sphalerite or zinc blende ("black jack"), chalcopyrite, arsenopyrite, dolomite, smithsonite, calamine, siderite, malachite, azurite, gypsum, barite, celestite, fluorite, limonite, göthite, hematite, chlorite, quartz, chalcedony, garnet, manganite, psilomelane, hausmannite, graphite, steatite, serpentine, etc.†

Structural varieties of limestone.—Limestones are called fissile or shaly if they split into layers an inch or less in thickness. Thin bedded and thick bedded are comparative terms, the first being applicable if the separate layers are from one to ten inches in thickness, the second if the layers are over two

*Galena limestone has also a stratigraphical signification in the Mississippi Valley, where it is used to designate a certain formation in the Lower Silurian rocks.

†Roth's Chemische Geologie, p. 160 *et seq.*

feet in thickness; when the layers are more than ten feet in thickness they are sometimes spoken of as massive, although some writers limit this term to the unstratified rocks. It may be found as nodules or concretions in other rocks, hence the terms nodular and concretionary. In most, if not all, of the veined limestones the vein is calcite of various colors, commonly white. A conspicuous and beautiful example of this is seen in the black marbles of Ireland, in which veins of white calcite traverse a black body. The term cavernous is applied to limestones with two significations: (1) meaning porous or full of small cavities, as sinters and some dolomites*; (2) in a more general sense, referring to caves or caverns. The first meaning might more properly apply to texture and the second to structure. The best example of the second is the Lower Carboniferous limestone in which so many caves exist in Kentucky, Southern Indiana, and elsewhere.

Textural varieties.†—Crystalline limestone is one composed wholly or chiefly of crystalline particles or crystals;‡ nearly all marbles come under this head. Saccharoidal is a term applied to certain varieties of crystalline limestone, which resemble loaf sugar in appearance. Granular (Körnige) limestone is one composed of distinct grains, whether crystalline or not, but this term more commonly refers to the crystalline, metamorphic limestones. It is used by some German writers as synonymous with marble,|| and by many others as synonymous with saccharoidal. Cryptocrystalline and microcrystalline are technical terms applied to rocks in which the individual particles cannot be distinguished by the naked eye. Fibrous limestone

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*Geikie, Text-Book of Geology, p. 94.

†Some writers use structure and texture as synonymous terms in geology, but they are here used with the distinction made by Jukes in his Student's Manual of Geology, 3d ed., 1871, p. 93, and by other writers, who use structure to designate the larger features as studied in field work, and texture, the minute characters as studied in a hand specimen.

‡Holocrystalline is a term proposed by Prof. Rosenbusch for rocks in which there is no amorphous material among the crystalline constituents.

||"Ganz Krystalline, Körnige Kalksteine oder echte Marmor," Einführung in die Gesteinslehre von A. v. Lassaulx, p. 85.

is one in which the separate crystals are arranged in bundles of distinct fibres, as found in satin-spar.* Amorphous limestone is one with no perceptible crystallization. There are two varieties of limestone with an earthy texture, namely: chalk and marl.

The word chalk† is derived from the Latin *calx*, the old name for lime. It is a white, soft rock composed in part of the microscopic remains of foraminifera, mollusks, echinoderms, and other organisms, and is generally a comparatively pure form of lime carbonate. It is not quite like any known modern deposit, but closely resembles the calcareous ooze of the deep sea. The name Cretaceous, given to a distinct geologic group of the secondary or Mesozoic rocks, is derived from Creta, meaning chalk, because of the abundance of chalk in that group. Until recently, chalk has been found only in the London and Paris basin, but a similar formation has lately been found in this country.

"Investigations in this Arkansas-Texas region, where the American cretaceous is best seen, show that we have, in a general manner, the equivalent not only of the upper but also of the middle and lower cretaceous beds of Europe, while chemical, stratigraphic and microscopic investigations prove conclusively that the culminating lithologic character of each of the two grand divisions of the lower and upper cretaceous beds of the region is cretaceous (chalky) both in name and in fact. In other words, the great mass of the cretaceous rocks in America, as in Europe, are, or were, mostly composed of more or less foraminiferous, chalky, infra-littoral sediments, while the upper arenaceous beds of New Jersey, Alabama, and the northwest, are only the littoral deposits of the upper cretaceous formation and hence are exceptional, and not representative of the whole period. Indeed, the cretaceous

*A variety of gypsum or lime sulphate is also called satin-spar, and is a more common mineral than the carbonate, satin-spar.

†Chalk as a geological term must not be confused with much of the so-called chalk of commerce, which is not chalk at all, but an artificial product composed mostly of the sulphate of lime.

formations of the Arkansas-Texas section are principally composed of chalks of different degrees of purity, both with and without flints, which facts throw great light upon the stratigraphic history of the cretaceous system, and prove that each of these formations culminated in long epochs of deep-sea sedimentation."

"The idea that true chalk does not occur in the United States, has also arisen from the lack of personal investigations of the formations of this southwestern region."*

There are numerous local varieties of chalk mentioned in works on the geology of England, as true white chalk, gray chalk, red chalk, Margate chalk, Norwich chalk, etc.

Marl is an earthy, crumbling, clayey limestone; the term, however, is so loosely used that it is sometimes applied to substances containing little or no lime. Many of the marls, notably the greensand or glauconitic marls of New Jersey and those of Arkansas, are valuable fertilizers. Marlstone is an argillaceous ferruginous limestone. Shell-marl is a white, earthy, crumbling deposit composed mostly of shells, and is largely a fresh-water deposit occurring in lakes and ponds. When it becomes consolidated it is called fresh-water or lacustrine limestone.

Oōlite (Rogenstein), or oōlitic limestone, is one composed of minute rounded concretions resembling the roe of a fish, hence the name. It occurs in all geological formations, and is now forming in the neighborhood of coral reefs and coral islands. Where compact it furnishes a very durable building stone. The oōlitic limestone of the Central Mississippi Valley in Missouri, Iowa, Illinois, Indiana, and Kentucky, on account of its elasticity, uniformity, and ease of working, furnishes a building stone which has acquired a national reputation.†

Pisolite (Erbsenstein), or pisolitic limestone, consists of concretions as large as a pea or larger, having usually a distinct

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*Annual Report of the Geological Survey of Arkansas, 1888, Vol. II., p. 153.

†The word oōlitic is here used in its lithological sense; it also has a stratigraphic meaning in European geology, as the name of several formations in the Jurassic system.

concentric texture. The last two varieties might be classed under concretionary texture.

Clastic or fragmental limestones include several varieties; chalk and marl might properly be classed under this head. If the fragments are angular in shape, it is called breccia, or brecciated limestone; if the fragments are rounded, as water-worn pebbles, it is called conglomerate, or conglomerated limestone. Some of the most ornamental marbles are of the last two varieties. If the fragments are shells, it is called shell limestone. The Coquina limestone of Florida is composed of a loose mass of broken shells which harden on exposure to the air. It occurs in layers from one inch to eighteen inches thick and is used as a building stone. The shells in this limestone have undergone no change and are the remains of species now living. Psammitic limestone is made up of grains of calcareous sand. Cryptoclastic or compact limestone is one in which the fragmental character is not revealed to the naked eye, and is frequently spoken of as amorphous.

Rottenstone is a decomposed siliceous limestone from which most or all of the lime has been removed, leaving a siliceous skeleton of the rock. A similar decomposition in some ferruginous limestones leaves a yellow skeleton of ochre.*

Argentite is a pearly lamellar variety of limestone with the the lamellæ more or less undulating. Aphrite approaches chalk in its softer, and argentite in its harder and more sparry variety. It is lighter than chalk, has a pearly lustre, silvery white or yellowish color, is soft and greasy to the touch, and more or less scaly in structure (Dana). Satin-spar and its varieties have been mentioned under calcite. (See p. 15.)

Genetic varieties of limestone.—Metamorphic limestone is a crystalline limestone in which the crystalline structure has been induced since the formation of the rock. (See Chapter XII.) Travertine, calc-sinter, and calcareous tufa are deposited by springs and streams, in some places as a light incrustation, and in others as a firm, solid bed many feet in thickness. These terms are used by some geologists (Dana, Geike) as synonyms,

*Geikie's Text-Book of Geology, p. 119.

while they are distinguished by other writers as follows: tufa is the loose, often impure, variety found incrusting twigs, moss, etc., along the streams; sinter, the porous forms found about hot springs; and travertine, the more solid form deposited in regular layers along the streams and frequently having a banded structure. The name travertine is said to be a corruption of Tibertine, and was originally given to the calcareous deposit on the river Anio, a branch of the Tiber, near Rome, where it forms a compact massive bed from which many of the public buildings of Rome are constructed. Stalactite is the lime deposit depending from the roofs of caverns; stalagmite, that found on floors of caverns, and is also applied by some to the incrustations on the walls of caverns, which by others are termed pilasters. "Drip rock" is a general term sometimes used for the last three. The so-called "Mexican onyx" and Oriental alabasters belong to these varieties.

Colors of limestone.—The most common colors in limestone are blue, gray, white, buff, black, red, brown, yellow, and green. The coloring matter in rocks is often difficult to determine, the percentage of the coloring impurity frequently being so small as to escape detection in chemical analysis. Blue may be due to carbonaceous matter or to the sulphuret or carbonate of iron.* Gray is commonly due to organic matter, but sometimes to diffused pyrites or dark silicates. White generally indicates a pure form, at least free from any appreciable amount of the metallic oxides; the white limestones as chalk and statuary marble are the purest forms known. Black may be caused by carbon, iron (magnetite), or a silicate rich in iron; in limestone it is commonly due to the carbonaceous matter in which case it becomes white on burning. Red and brown are generally due to iron oxide, hematite causing the first and limonite the second. These colors are sometimes caused by rhodochrosite or manganese carbonate and sometimes by both iron and manganese. Yellow indicates the presence of hydrated peroxide of iron. Green may be due to some hydrous magnesian silicate (chlorite, talc, serpentine), ferrous silicate,

*Azurite gives a bright blue, but its occurrence is rare and confined to small areas.

or copper carbonate (malachite). The last may commonly be distinguished by its brighter color.

Varieties of limestone based on usage.—Common limestone signifies that which is used in ordinary rubble and ashlar work, and for burning lime. Ornamental limestone is synonymous with marble, which see. Lithographic stone is a very smooth, even-grained, compact limestone, usually of a buff or drab color.

Hydraulic limestone is one which when burnt and mixed in mortar possesses the property of hardening under water. (See Chapter VI.)

Local names.—Commercially it is customary to name a stone from the place where it is quarried. All such names are more or less local in their use, and the list could be indefinitely extended.* The best known in Arkansas is the Batesville limestone. The Bedford or Indiana stone named from Bedford, Indiana, comes more nearly having a national reputation in America than any other. The prototype (commercially, not geologically) of this in England is possibly the Bath oölite or the Portland limestone, both of which names have also a geological signification in that country; in France it is possibly the Cæn stone.

Geologic varieties.—Limestones are frequently known by the place which they occupy in the geologic column. Most of these names, however, are geographic terms which have acquired a geologic significance. The name is commonly taken from the place where the rock is first studied, and later applied to limestones in other places found to be its stratigraphic or paleontologic equivalent. Thus the name Trenton limestone was first applied to the limestone found on Trenton River in the State of New York, but the name has since been extended to limestones of the same geologic age over the central and eastern United States. Other widely known limestones are the Galena, Cincinnati, Black River, Niagara, Keokuk, St. Louis, and Chester, in the United States; and the Bath oölite and Portland limestone in England, with many others more local in their application. Other limestones, the names of which

*The most complete accessible record on this subject is the Census Report.

have acquired a geologic significance, have been named on some other basis. Thus the Archimedes, Pentremital, and Maclurea limestones have been named from a characteristic, fossil found therein, and the Mountain limestone from the fact that it forms ranges of hills in England.

Varieties of limestone based on appearance.—Limestones are sometimes named from some peculiar property which would not bring them in any of the above classes, and which are included under the not very scientific term appearance. Such is the dendritic limestone, or dendrite, so named from the black tree-like markings, which are made by iron or manganese oxides. Neither Nature nor any of her students have yet explained why these oxides should gather in such fantastic forms. Variegated limestone, which includes some of the choicest marbles, is one with two or more colors generally interwoven with such a charming irregularity as to give the stone a beautiful, often fantastic appearance. Bird's-eye limestone is a dark-colored rock with veins, streaks, and spots of white calcite scattered through it in such a way as to suggest birds' eyes. The name has now a stratigraphical signification, being used in the State of New York to distinguish the lower part of the Black River formation of the Trenton period. The same term is applied to a fossiliferous limestone in Iowa which contains a species of fossil coral, (*Acervularia davidsoni*). Professor Mahan mentions* a bird's-eye limestone named from the "peculiar fossil" *Fucoides demissus.*

Nearly every limestone is fossiliferous, but is not commonly so named, unless the fossils are abundant or it contains a fossil peculiar to a single geologic formation. It sometimes receives the general term fossiliferous, or it may be named from the kind of fossils it contains as, coral limestone, crinoidal or encrinital limestone, shell limestone; or even more specifically, Nummulitic, Archimedes, Pentremital, and Maclurea. The Nummulitic limestone is used extensively as a building stone in France and Egypt, the Great Pyramid being built of it. Fine marbles are found in nearly all these varieties.

*Civil Engineering, 2d ed., 1875, p. 10.

CHAPTER IV.

Geologic and Geographic Distribution of Limestones.

Probably no rock has a wider distribution,* is more generally recognized, appears under so many forms, or has as many different uses as limestone. To treat of its distribution in detail is quite impossible, yet a brief outline of the subject is desirable from both an economic and scientific standpoint.

A general idea of the wide geologic and geographic distribution of limestones may be obtained from the following table which aims at nothing further than showing the great activity of lime-producing agencies through past time:

General distribution and thickness of limestones.

System.	Group.	Place.	Thickness in feet.
Psychozoic	Pleistocene	Pacific Ocean (Coral islands)	2,000
Cenozoic or	Tertiary	Central Asia	3,000 (?)
Mesozoic	Cretaceous	England	1,200
	Jurassic	France	2,700
	Triassic	Eastern Alps	5,000
Paleozoic	Permian	England	600
	Carboniferous	England	5,000
	Devonian	New York and Michigan	350
	Silurian	Cape Gaspé	8,200
	Cambrian	Appalachian Mountains	
Archæan	Laurentian	Canada	3,500
			31,550

Laurentian.—The rocks of Laurentian age include the heavy beds of crystalline limestone in Canada,† which consists of four

*"In the various estimates made of the extent of the limestone formation it is computed that in one or other of its varieties it occupies three-fourths of the earth's surface." Portland Cement, by Reid, p. 39.

†Geological Survey of Canada, Report of Progress from its Commencement to 1863, p. 45.

distinct beds, aggregating 3500 feet in thickness. It is generally coarse-grained, sometimes saccharoidal, having the prevailing color of white, but gray, blue, red, yellow, and dark green varieties occur.

CAMBRIAN GROUP.

Some beautiful marbles and building stones occur in the Cambrian rocks, the most noted of which in the United States are found in Vermont, Minnesota, New York, and Wisconsin. The Winooski colored marbles occur in the Potsdam in northern Vermont. The dolomites and dolomitic limestones of the Shakopee and St. Lawrence formations in Minnesota furnish an abundance of durable and popular building stone.*

THE SILURIAN GROUP.

The Calciferous terrane includes thick limestones in Newfoundland, and heavy beds of magnesian limestone in Arkansas, Missouri, Iowa, Illinois, and Wisconsin. The magnesian limestones are abundant in North Arkansas, and produce excellent building stone. The Quebec includes part of the Vermont marbles,† limestones in Newfoundland, and part of the Knox group in Tennessee. The Chazy includes limestones in New York, and Canada, and part of the Vermont marbles.

The Trenton.—The Trenton rocks are better known, more widely distributed, and contain limestones of greater economic value than any other subdivision of the Silurian. In Tennessee it includes the blue Maclurea limestone, the East Tennessee variegated marbles, and the Nashville limestone. In Arkansas it is characterized by the St. Clair marble of Independence, Izard, Stone, and Searcy counties, and possibly by the heavy bed of blue Izard limestone under it. Through the northern part of the Mississippi Valley, where it is known as Galena limestone, it is a lead-bearing magnesian rock; it abounds in Iowa, Illinois, and Wisconsin. In Minnesota much

*The Geological and Natural History Survey of Minnesota, N. H. Winchell, Vol. I. of the Final Report, pp. 156, *et seq.*

†T. S. Hunt, Am. Jour. of Sci. for 1861, (2) XXXI., p. 402.

valuable building stone is found in this group.* The Cincinnati limestones of Ohio; the Glenn's Falls black marble, the Bird's-eye limestone, the Hudson River limestone, and the Black River limestone of New York; and the Cape Girardeau limestone of Missouri all belong to the Trenton. It is abundant in Canada around Ottawa and along the north side of the St. Lawrence from Montreal nearly to Quebec, and at intervals further east. On the island of Anticosti is a total thickness of nearly 2400 feet of limestone, about 1200 feet being in the Trenton. The Trenton limestone is valuable both on account of the building and ornamental stones obtained from it, and the economic products found in it, the chief of which are the lead and zinc ores in the upper Mississippi region and the petroleum and gas in the Ohio Valley.

The Niagara.—The Niagara contains much valuable limestone, which is used for lime, cement, and building stone. The color is commonly dark bluish gray to drab. It is sometimes magnesian. In structure the Niagara limestone is often nodular or concretionary, and in some parts of the West it abounds in chert, the fossils all being siliceous. At Chicago it contains large quantities of mineral oil, which has been extracted to some extent, but not in paying quantities. The coralline limestone of the Helderberg Mountains belongs to this group, as does the Meniscus limestone of West Tennessee (Dana). The Galt or Guelph limestone of Canada and the Leclaire limestone of Iowa belong in the Niagara group. In Ohio the Niagara limestone forms the lower part of what was formerly known as the Cliff limestone. In eastern Indiana and in western New York it is extensively quarried for bridge piers and heavy masonry, and for lime burning; at Lockport, N. Y., an encrinital variety is used as marble. It is quarried at Joliet, Illinois, where it is known as the Athens marble.† It is also quarried in Illinois at Lemont, Lockport, Batavia, and within the city limits of Chicago.

The Salina.—The Salina contains but little limestone, and is

*Geological and Natural History Survey of Minnesota, Final Report, Vol. II.

†Geological Survey of Illinois, Vol. III., 1868, p. 253.

marked by the Onondaga Salt-group of New York, in which state it contains some hydraulic limestone.

The Lower Helderberg.—The Lower Helderberg is named from the Helderberg Mountains in New York, where it is found beneath the Upper Helderberg, which is Devonian. It spreads over a large area in the United States, and is marked by heavy limestone strata, the lower beds of which are called the Water-lime group on account of its being used for hydraulic lime. It is a thin-bedded, drab-colored or bluish, impure limestone. It is found in southern Illinois as a siliceous limestone. Light blue limestone of this group occurs in West Tennessee, with a maximum thickness of about 100 feet. The limestones of this period in Pennsylvania show a thickness of 350 feet for the Water-lime group, and 100–250 feet for the remainder of the group. It is found in places in northern Maine, but at Cape Gaspé it reaches its maximum thickness of 2000 feet. This, however, is not all Lower Helderberg, but a small part of it is probably Oriskany (Dana). The limestones of this group are famous for their hydraulic properties, supplying the Buffalo Cement Works and other similar establishments in New York and Ohio. Other subdivisions of the Lower Helderberg in New York include the Pentamerus, Catskill, Encrinal, and Upper Pentamerus limestones, the Water-lime being the lowest and Upper Pentamerus the highest.

The Oriskany.—The Oriskany contains comparatively no limestone in New York and the Appalachian system, but there is some in the Mississippi basin, while in the eastern border region it is mainly composed of limestone (Dana).

THE DEVONIAN GROUP.

In New York the Corniferous terrane of the Devonian group is the only one prolific of limestone. It extends through New York and westward through Canada and the interior basin, having as wide a range as the Niagara limestone. At Enniskillen, Canada, and at Terre Haute, Indiana, it contains mineral oil.

In New York the Onondaga limestone is quarried in many

places as a building and ornamental stone, furnishing a fair quality of marble. It has a dark grayish color in New York, but in the interior basin it is usually light gray, drab or buff, having an oōlitic texture in places. In Iowa both common and magnesian limestones are quarried from this group.* In Minnesota Devonian limestone suitable for building stone and lime rock is quarried.†

The Hamilton terrane contains thin beds of limestone in New York and Illinois.

In England the Devonian rocks contain the Plymouth limestone, which is sometimes coralline, and yields the Madrepore marbles, the prevailing tints of which are various shades of gray, with veins of white and yellow.

THE CARBONIFEROUS GROUP.

The Carboniferous group is divided in the United States into Lower Carboniferous‡ and Carboniferous or Coal Measures, the first of which is remarkable for its heavy beds of limestone, which are more widely distributed than those of any other period, extensive beds of this age being found in Europe, Asia, and Australia, as well as in North America. In the Appalachian region in Pennsylvania, where the Silurian limestones reach such a great thickness, the Carboniferous rocks are mostly sandstones and shales, and it is in the Mississippi Valley that the limestones are best developed. Geikie's excellent description of the limestones of this period is here quoted :||

"The materials of which the Carboniferous system is built up differ considerably in different regions; but two facies of sedimentation have a wide development. In one of these, the marine type, limestones form the prevailing rocks, and are often visibly made up of organic remains, chiefly encrinites,

*C. A. White, Geology of Iowa, 1870, Vols. I. and II.

†Geological and Natural History Survey of Minnesota, Final Report, Vol. II.

‡Synonyms: Subcarboniferous and Mississippian. The Lower Carboniferous limestones of America correspond to the Carboniferous or Mountain limestone of Europe.

||Text-Book of Geology, p. 718.

corals, foraminifera, and mollusks. According to Dumont's researches in the Carboniferous Limestone of Belgium there are two main types of limestone: (1) the massive limestones formed by reef-building corals and coralloid animals, and disposed in fringing reefs or dispersed atolls, according to their nearness to or distance from the coast of the time; and (2) the detritic limestones, consisting either of an aggregation of crinoid stems or of coral-debris, and often stretching in extensive sheets like sandstone or shale. The limestones of both types assume a compact homogeneous character, with black, grey, white, or mottled colors, and are occasionally largely quarried as marble. Local developments of oölitic structure occur among them. They also assume in some places a yellowish, dull, finely granular aspect and more or less dolomitic composition. They occur in beds sometimes, as in Central England, Ireland, and Belgium, piled over each other for a depth of hundreds of feet, and in Utah for several thousand feet, with little or no intercalation of other material than limestone. The limestones frequently contain irregular nodules of a white, grey, or black flinty chert (phtanite), which, presenting a close resemblance to the flints of the chalk, occur in certain beds or layers of rock, sometimes in numbers sufficient to form themselves tolerably distinct strata.* These concretions are associated with the organisms of the rock, some of which, completely silicified and beautifully preserved, may be found imbedded in the chert."

The limestones of Arkansas, in the White River valley, fall under thc second class, or the detritic limestones.

In Ohio this limestone is less than 20 feet in thickness but it increases westward, reaching 1100 to 1200 feet in Illinois and Missouri. While there is comparatively no limestone in this formation in Pennsylvania, it appears in Virginia and continues through Tennessee into Alabama and Mississippi, increasing in amount to the southwest.

In Illinois the rocks of Lower Carboniferous age are divided into five formations: Kinderhook, Burlington, Keokuk, St.

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*Renard, Bull. Acad. Roy. Belg. (2) XLVI., p. 9.

Louis, and Chester; most of the terms are used in the neighboring states. The *Kinderhook* receives its name from Kinderhook in southern Illinois and includes the Chouteau limestone and the Lithographic limestone of Missouri, the Goniatite limestone of Rockford, Indiana, and the Iowa marble. The *Burlington* limestone (the Encrinital limestone of Owen) varies in different localities from 25 to 200 feet in thickness. While much of it is excellent building stone, for which it is used at Burlington, Iowa, in places it is injured for this purpose by the cherty layers and nodules of hornstone which it contains. The *Keokuk* formation (Lower Archimedes of Owen) contains thin-bedded, cherty layers below, gray limestone in the middle, and shaly argillaceous magnesian limestone above (Dana). The stone is quarried extensively as a building stone at Keokuk, Iowa, whence the name; also at Nauvoo, Illinois, and at intervening points along the Mississippi River.

The *St. Louis* (Concretionary limestone of Owen; Warsaw limestone of Hall in part) from a commercial standpoint, is the most important of the Lower Carboniferous limestones, and is extensively quarried in Missouri, Illinois, and Indiana. The evenly-bedded limestone of St. Louis and Alton, the oölitic limestones of Bedford, Bloomington, Elletsville, and Stinesville, in Indiana, have given this the reputation of the finest limestone for building purposes in the United States. It is also quarried extensively at Kilbourne, Iowa, where it is a yellowish, buff-colored limestone, and at Pella, Iowa, where it is the common gray limestone.*

The limestones of the *Chester* formation occur in three or four beds, with some intercalated shale and sandstone, occasionally 600 feet thick.

In North Arkansas the rocks of the Lower Carboniferous series are divided into the Boston and Osage groups, and contain several beds of limestone. The whole series has a total thickness of 1200 feet in southern Illinois, 1150 feet in Missouri, 390 feet in Iowa, while in Tennessee it is 1370 feet,

*C. A. White, Geology of Iowa, Vol. II., 1870, p. 315.

not all of which is limestone. It is also found in considerable thickness in the Rocky Mountain region.

In England it is made up of corals, crinoids, and mollusks, and is of a gray, blue, or yellow color. Some of its beds produce black marble, some reddish, others variegated; the whole attains a thickness of 5000 feet.* It is a massive well-bedded limestone, varying from a compact homogeneous to a distinctly crystalline texture and rising into ranges of hills, whence its name Mountain limestone. In Ireland it reaches a thickness of 3600 feet, including some shale and chert.

In Belgium and northern France the Carboniferous limestone attains a thickness of nearly 2500 feet. In eastern Europe the Carboniferous limestone is not so well developed, giving way to shales, sandstones, and conglomerates. In Asia it forms extensive beds; in China the equivalent of the Carboniferous limestone appears to be a massive brown bituminous limestone; while in Australia this limestone occurs intercalated with sandstones, conglomerates, and shales.

The Coal Measures.—There are but few limestones of note or of commercial value in the Coal Measures. The great limestone south of Pittsburg is nearly seventy feet thick, and occurs in the upper Coal Measures. The thin limestones of the Coal Measures in Pennsylvania, Virginia, and Tennessee, thicken to the west, forming heavy beds in Indiana, Illinois, western Kentucky, Missouri, and Nebraska, and in the Rocky Mountains reach a thickness of over 1000 feet.

The Permian.—The Permian contains but little limestone of value in America. In England it contains a somewhat extensive bed of magnesian limestone, which is quarried to a considerable extent for building purposes.

TRIASSIC GROUP.

The only limestone of note found in the Triassic in America is the Potomac marble, a pudding-stone rock exposed and quarried at Point of Rocks, Maryland, and an impure yellowish or gray hydraulic limestone, at Southbury, and near both

*On Building and Ornamental Stones, E. Hull, pp. 195–6.

Middlefield, Connecticut, and Springfield, Massachusetts. In Germany it contains heavy beds of limestone found in the Muschelkalk (shell limestone) division, having a total thickness of from 600 to 1300 feet (Geikie).

But it is in the Alps that the Triassic rocks reach the greatest development, the entire thickness of which is not known exactly, but must reach many thousand feet. In the western Alps this period is marked by the famous Carrara marble.

THE JURASSIC GROUP.

There are no Jurassic limestones in the eastern United States, but in the Uinta range there are two beds, from 200 to 300 feet thick, both fossiliferous. In the Wasatch Mountains is a heavily bedded limestone.

In England the Jurassic limestone is in a commercial way what the Carboniferous is in America. Its most important beds are the Inferior Oōlite, the Great or Bath Oōlite, the Corallian, and the Portlandian.

In France the Triassic rocks contain numerous beds of limestone, the most important of which is the Cæn stone, one of the most noted building stones of the world. The Cæn stone is used extensively in France and to some extent in England, America, and other countries. It is fine-grained and uniform in texture, which makes it valuable for fine sculpture; is very light colored, being nearly as white as chalk; and of light weight, weighing from 100 to 142 pounds per cubic foot.

THE TERTIARY GROUP.

The principal Tertiary limestones in America are the shell rock quarried at St. Augustine for building purposes, locally known as Coquina; the Orbitoides limestone of the Southern States; and the white limestone of Alabama.

Much of the architectural beauty of Paris is due to the abundant use of the beautiful Middle Eocene limestones of the Paris Basin. They also abound in the south of France, and most of the buildings of Marseilles, Montpelier, and Bordeaux are constructed of them.

The Nummulitic limestone formation running through the centre of the Eastern Continent, in its extent even surpasses the Carboniferous limestone. It has been traced from the Pyrenees eastward, through the Alps and Appennines into Greece, and through the Carpathian and Balkan Mountains into Asia Minor; thence through Persia and Central Asia to the coast of China and Japan. On the south side of the Mediterranean it occurs in the Barbary States and Egypt. In places it attains a thickness of several thousand feet, and is a hard, compact, occasionally crystalline rock passing into marble. It has been so fractured and folded that the strata have been elevated into mountains, sometimes 10,000 feet, and in the Himalayas more than 16,000 feet high. This rock has been largely quarried in Egypt, where it was used in constructing the great pyramid of Cheops, and presumably some of the other pyramids. It is found in the ruins of Baalbec, and is used as a building stone in Aleppo and some of the cities of the Holy Land.

GENERAL OBSERVATIONS.

Limestone has been almost continually forming somewhere from the time of the very earliest stratified rocks to the present. There appears to be a large break in the continuity from the Laurentian rocks to the bottom of the Lower Silurian, over what is called the Huronian period, which is no doubt due in part to the incompleteness of the record.

It will be noticed that there are long and short limestone-making periods, all more or less local in extent. In America the Silurian and Lower Carboniferous are the great limestone-making periods, while in Europe the greatest limestone beds have been formed since Paleozoic times.*

*For details on the distribution of limestone in the United States, see the various State Geological Survey Reports; the United States Geological Survey Reports; Tenth and Eleventh United States Census; Smithsonian Report for 1886, Part II.; Stones for Building and Decoration, by G. P. Merrill, N. Y., 1891.

CHAPTER V.

LIMESTONE AS A BUILDING STONE.

Limestone is one of the most common and useful of building stones, being used for pavements, foundations, retaining walls, abutments, bridge piers, and superstructures. For costly buildings and those intended to be lasting, the quality of the stone used is of great importance, and too great care cannot be taken in its selection. The chief points to be observed in selecting a building stone are its durability, color, workability, and cost.

INHERENT PROPERTIES AFFECTING THE DURABILITY OF BUILDING STONES.

Durability is an essential property of a building stone, for, however excellent a stone may be in other respects, if it lacks durability it is comparatively useless for structural purposes. The importance of the subject is such as to merit more than a brief mention.

Chemical composition.—The chemical composition of a rock or of its cementing material is an inherent source of strength or weakness. As a rule, the more impurities found in limestone the less durable it becomes; magnesia, however, is an exception, as dolomite is generally considered more durable than ordinary limestone. Yet in general a pure limestone is more durable than a mixture of limestone and dolomite, for the reason that the tendency of magnesian limestones is to become more open and porous than pure limestones, thus admitting meteoric water, which dissolves the lime carbonate and destroys the texture of the stone, causing it to crumble. Homogeneity, though a mechanical rather than a chemical property, is of prime importance, as frequently an impure limestone with the impurities evenly distributed, will be more

durable than a purer one with the impurities unevenly distributed. Argillaceous matter, owing to its tendency to absorb moisture and to crumble to pieces, becomes very injurious when it occurs in layers or patches.

If the cementing material should be subject to decomposition or disintegration, the strength of the stone is greatly impaired, the greatest danger being from argillaceous material or protoxide of iron. The sesquioxide of iron is dangerous only in the presence of moisture and organic matter, while under other conditions it may serve as a bond of strength.* Danger from this source is more to be guarded against in crystalline or granular stone than in compact varieties.

Iron sulphide or iron carbonate is frequently a source of discoloration and even of destruction, if present in sufficient quantity. The sulphide of iron is more liable to decomposition when it is in the form of marcasite than in the form of yellow pyrite, and is less destructive in dry places than in moist ones, as in the presence of moisture it not only forms the oxide known as iron rust, but at the same time produces sulphurous and sulphuric acids which act on the lime, changing it to sulphate of lime or gypsum. Often the only effect of the iron, if present in very slight quantities, is to mellow the stone, that is to produce a yellow tint with age. Organic matter sometimes causes decay and if present as petroleum causes discoloration.† The oil is beneficial, however, in keeping water out of the pores, thus enabling it to better withstand the freezing of a cold climate.

Texture.—The texture of a limestone used for building purposes is of prime importance. The size of the particles frequently affects the durability of the rocks, the fine-grained and compact rock, as a rule, being the more durable. Professor Hall says: "So far as the marbles are concerned, all the crystalline forms, be they coarse or fine, may be strong or

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*The Geology of Minnesota, Vol. I., p. 189.

†The Niagara limestone quarried at Chicago is much disfigured by the petroleum (drawn out by the heat of the sun) both on account of the dark color and the dust which it collects.

weak. The fine-grained marbles, which show scarcely a crystalline structure, or such only as the calcareous muds might take on in their metamorphism, are the most durable stones of this kind."*

In the Arkansas limestones, the gray limestone of the chert series at Batesville is finer grained than in the counties further west, and, so far as can be interpreted from quarry exposures, is more durable. The compact, fine-grained Izard limestone is more durable than the loose-textured Archimedes limestone, which, however, is not wholly due to difference in porosity. Want of cohesion of the particles, either from poor or insufficient cementing material, is a source of destruction.

Coarsely fossiliferous rocks are as a rule not durable, owing to the unequal weathering of the fossils and matrix; the fossils, being generally the more durable, may often be seen covering the weathered surface of the rock. Veined stones are liable to present an uneven surface, due to the relative durability of the vein material and the rock mass. Hence, homogeneity of texture as well as of composition is desirable; yet a rock should not be thrown aside hastily because it lacks this property, as many heterogeneous rocks are strong, durable, and valuable; the value, as in the case of variegated marbles, often depending upon the mixture.

EXTERNAL AGENCIES AFFECTING BUILDING STONES.

The external agencies which affect building stones directly or indirectly according to the positions they occupy are changes of temperature, chemical action, and abrasion.

Changes of temperature.—Sudden and great changes of temperature have a very destructive effect which is much more manifest in a moist climate than in a dry one, and more active in a cold climate than in a warm one. Cleopatra's Needle, which stood for centuries in the comparatively dry and equable climate of Egypt, began to crumble in a few years in the more trying one of New York. In cold weather the

*Report on Building Stones, by James Hall, from the Thirty-Ninth Annual Report of the New York State Museum, p. 36.

water which soaks into the stone freezes, breaking off little chips of the rock by its expansion; hence, other things being equal, the more porous the rock, the more it is affected by freezing. In very hot weather a sudden shower falling upon a highly heated stone cools it so suddenly as to crack the surface. While not so destructive as the violent changes of temperature, even the ordinary diurnal changes produce a strain upon the stone which is necessarily injurious. Observations on the pendulum in Bunker Hill Monument show that the stones in the monument are scarcely at rest for a moment, constantly twisting and bending from the changes of temperature on the different sides.*

Chemical agencies.—Acids and acid vapors, so abundantly produced in the vicinity of manufacturing cities, have a destructive action on limestone.† The sulphurous and sulphuric acids from the sulphur of the coal are probably the most destructive. Carbonic acid, a less active but more abundant agent, is active only in the presence of water. Geikie, in a series of observations on the weathering of tombstones, observes‡ that superficial solution is mainly due to sulphuric acid, but that it is frequently retarded by the formation of a peculiar gray or begrimed crust consisting principally of the sulphate of lime, while internal disintegration is mainly due to the action of carbonic acid in the permeating rain-water, whereby the separate particles are partially dissolved and the

*"This cause (changes of temperature) operating everywhere, at all times and through all seasons, is a far more active agent in the destruction of buildings than all the others operating together; and though it may sometimes require years for an appreciable change to be accomplished upon a sound material, it is nevertheless constantly going on, however slow the change may be." James Hall, Report on Building Stones, p. 37.

†The difference in degree of durability between rock exposed in a city and in the country atmosphere is shown in St. Paul's Cathedral, London, which is "fast mouldering away," while frustra of columns and other blocks quarried at the time the cathedral was building and left in the quarry on Portland Island are still sound. Smithsonian Report, 1886, Part II., p. 346.

‡Geological Sketches at Home and Abroad, by Archibald Geikie, p. 164 *et seq.*

mutual adhesion destroyed. Hydrochloric and nitric acids are equally injurious, but not abundant.*

It is generally believed that the growth of confervæ, algæ, lichens, and mosses upon the rocks hasten their decay by giving rise to organic acids which corrode the surface and cause the rock to crumble.† Professor Hall says that this growth hastens disintegration and by accumulating fine dust, floated by the atmosphere, becomes points for the absorption of water which on freezing still further roughens the surface. "It should not be forgotten, however," says Professor Hall, "that any stone giving root to lichens is not one of those which most easily disintegrates. The lichen-covered rocks in nature are usually those of great strength and durability."‡ Observations on the limestones of Arkansas lead to the conclusion that lichens occur only on the most durable rocks, and it seems therefore that their presence is an evidence of the durability of those rocks.

Abrasion.—Abrasion of building stone may be caused by feet, water, or sand-laden wind. The first affects sills, steps, floors, and walks. Limestone resists wear of this kind longer than sandstone, but is objected to for outdoor use, because when wet it becomes slippery.||

Abrasion by water will affect the durability of bridge piers, abutments, wharves, defective pavements, etc. Sand-laden

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*"Every flash of lightning not only generates nitric acid, which, in solution in the rain, acts upon the marble, but also by its inductive effects at a distance produces chemical changes along the moist wall, which are at the present time beyond our means of estimating." Joseph Henry, Amer. Jour. of Sci., November, 1856, p. 31. For nitric acid in rain-water, see Trans. Kan. Acad. Sci., 1889, (XII.) pp. 21–24.

†Geology of Minnesota, Vol. I., p. 188.

‡Report on Building Stones, p. 38.

||A good example of the comparative durability of sandstone and limestone is exhibited in the steps of the Science Building of Missouri State University, Columbia, Missouri. These steps have now been in constant use for seventeen years. The upper step, which is of sandstone, has worn in the middle 3 inches; the second of limestone, 0.5 in.; the third of limestone, 0.45 in.; the fourth of limestone, 0.3 in.; the fifth of limestone, 0.15 in.; the sixth of limestone, 0.12 in. G. C. Broadhead, in the Building Trades' Journal, August, 1888.

wind abrades stones,* but it is not an agency of importance in this connection. Many of the tombstones in the cemeteries at New York show much greater defacement on the eastern faces than on the western,† which fact is due to the sea-breezes.

METHODS OF ASCERTAINING THE DURABILITY OF BUILDING STONE.

There is no absolute method of determining the durability of a building stone save by actual experience. The methods employed simply enable us to compare the results obtained with those obtained by similar tests upon rocks which have been tested by time and actual experience—the only infallible proofs of durability.‡ The methods by which a comparative idea of the durability of a stone may be determined are: analysis, action of acids, specific gravity, porosity, sudden changes of temperature, and crushing test.

Chemical analysis.—A chemical analysis frequently reveals injurious elements not otherwise noticed, and is a further aid in interpreting color, and probable or positive change of color.

Acid tests.—Experiments are occasionally made to show the action of various acids in solution and some in a gaseous state upon the different building stones. The more common acids experimented with are carbonic acid, weak solution of sulphuric, and nitric and sulphurous acid fumes. It is doubtful whether such experiments have any practical value which cannot be inferred directly from a chemical analysis.

Specific gravity test.—The specific gravity of a stone, which is generally indicative of its porosity, has a relative and somewhat doubtful value, and is useful only when taken in comparison with that of other stones of similar composition.

There are several methods of obtaining the specific gravity,

*Smithsonian Report, 1886, Part II., p. 335; Proc. A. A. A. S., IX., p. 216.

†A. A. Julien, Trans. N. Y. Acad. Sci., April 30, 1883, p. 129.

‡"The artificial methods of trial of stone, now occasionally in vogue, * * * are, from their obsolete antiquity, imperfection, or absolute inaccuracy, unworthy of the age of so honorable a profession." Dr. A. A. Julien, in Trans. N. Y. Acad. Sci., p. 76.

the most common being to divide the weight of the dry stone in air by the difference between its weight in air and its weight in water. In getting the weight in water, distilled water should be used and the sample left in the water until all bubbles have escaped and the stone is saturated, which is frequently not done. Professor Francis A. Wilber in testing the New York building stones took the further precaution to use boiled water and to place the vessel containing the specimen under the receiver of an air pump.* Gillmore removes all sharp corners from the sample, making it as nearly water-worn as possible, then weighs it in air and immerses it in water, allowing it to remain until all bubbling ceases, after which he weighs it again. It is then taken out, the unabsorbed water is removed by blotting-paper, and it is weighed in its saturated condition. The specific gravity is then found by dividing the weight of the dry stone by the weight of the saturated stone minus its weight in water.†

Porosity test.—Dr. Hunt says: "Other things being equal, it may probably be said that the value of a stone for building purposes is inversely as its porosity or absorbing power."‡ But other things are not always equal, and some very porous stones are really more durable than less porous ones, because they part with the moisture more readily. In cold climates the greatest injury results from the freezing of the absorbed water, which upon expansion bursts the particles asunder. It follows then that a rock which retains its moisture is more liable to injury than one that dries readily.

The absorption percentages and specific gravity of marbles and limestones, compared with granites and sandstones, and obtained as the average of a number of samples of New York and New England rocks, are as follows:‖

*Bulletin Vol. II., No. 10, New York State Museum, p. 357.

†Annual Report of the Chief of Engineers, U. S. A., for 1875, App. II., p. 7.

‡Chemical and Geological Essays, 2d edition, p. 164.

‖Bulletin No. 10 of the New York State Museum, pp. 375–6.

Specific gravity and porosity of building stones.

	Specific gravity.	Per cent. of absorption (porosity).
Marbles	2.780	0.127
Limestones	2.728	0.122
Granites	2.708	0.591
Sandstones	2.620	2.758
Cæn limestone (France)	1.839	16.050

The porosity of the stone is shown by the ratio or percentage of absorption, and is found by dividing the weight of the saturated stone minus the weight of the dry stone by the weight of the dry stone.

Test by changes of temperature.—Two opposite methods are used to determine the ability of a stone to withstand sudden changes of temperature; one of these is by alternate freezing and thawing, the other by a sudden cooling from high temperature. The first, if repeated often enough, will give some idea of the ability of the stone to stand cold climates. The artificial processes usually employed, however, are not as reliable as exposure in a cold climate; the best method, therefore, is to have the samples spend one or more winters in a cold climate, having them removed to a warm room and thawed out occasionally during the protracted cold weather.

Brard's process, which is sometimes used as a substitute for freezing and thawing, consists in boiling the sample to be tested in a saturated solution of sulphate of soda and then allowing it to dry, when the crystallization and consequent expansion of the salt which has been absorbed into the pores are supposed to exert an action similar to that of ice. The process has not come into general use.

Professor Merrill says: "It seems, however, to be well proven that of all stones granite is the least fire-proof, while the fact that certain of the fine-grained siliceous sandstones are used for furnace backings would seem to show that if not absolutely fire-proof, they are very nearly so."* Dr. Cutting's experiments, on the accompanying table, show that, up to the point

*Stones for Building and Decoration, p. 356.

*The effect of heat on various building stones.**

Kind.	Locality.	Specific gravity.	Weight per cubic foot in pounds.	Ratio of absorption.	First appearance of injury. Degrees F.	First appearance of cracking or crumbling. Degrees F.	General cracking and friability. Degrees F.	Rendered worthless. Deg. F.	Melted or destroyed. Deg. F.
1. Light colored granite	Hallowell, Me	2.638	164.8	1-790	860	900	950	1,000	1,100
2. Red granite	Stark, N. H	2.631	164.1	1-534	600	700	800	850	950
3. Carter's Quarry granite	Woodbury, Vt	2.654	165.8	1-784	800	900	950	1,000	1,200
4. Syenite	Quincy, Mass	2.660	166.2	1-650	750	800	850	900	1,000
5. Common granite	Woodstock, Md	2.648	165.5	1-394	700	750	800	900	900
6. Old Dominion Quarry granite	Richmond, Va	2.674	167.7	1-402	750	800	850	900	1,000
7. Light colored granite	St. Cloud, Minn	2.690	168.2	1-290	700	700	800	850	900
8. Sandstone	Portland, Conn	2.380	148.7	1-27	850	900	950	1,000	1,100
9. Sandstone	Seneca, Md	2.410	150.6	1-40	900	1,000	1,100	1,200	1,200
10. Sandstone	Nova Scotia	2.424	151.5	1-240	900	950	1,000	1,000	1,100
11. Potsdam sandstone	McBride's Corners, O	2.333	145.8	1-28	800	850	900	1,000	1,100
12. Berea sandstone	Berea, O	2.254	140.8	1-20	850	900	950	1,000	1,000
13. Limestone	Baltimore, Md	2.917	181.8•	1-340	900	1,000	1,100	1,200	1,200
14. Limestone	Bedford, Ind	2.478	154.8	1-280	850	900	1,000	1,200	1,200
15. Cincinnati limestone	Hamilton county, O	2.204	137.7	1-28	850	900	950	1,200	1,200
16. Potts' blue limestone	Springfield, Penn	2.666	166.6	1-280	850	850	900	1,000	1,200
17. Dolomite limestone	Owen Sound, P. O	2.571	160.6	1-480	850	900	1,100	1,200	1,200
18. Trenton limestone	Montreal, P. Q	2.706	169.1	1-316	900	950	1,000	1,200	1,200
19. Limestone	Isle La Motte, Vt	2.696	168.5	1-320	950	1,000	1,100	1,200	1,200
20. Tuckahoe marble	Westchester county, N. Y	2.794	174.6	1-298	900	1,000	1,200	1,200	1,200
21. Ashley Falls marble	Ashley Falls, N. Y	2.742	171.3	1-280	900	1,000	1,100	1,200	1,200
22. Snowflake marble	Westchester county, N. Y	2.848	178.0	1-380	950	950	1,000	1,200	1,200
23. Tennessee marble	Dougherty's quarry, E. Tenn	2.711	169.4	1-320	950	950	1,000	1,200	1,200
24. Duke marble	Near Harper's Ferry, Va	2.812	175.7	1-340	1,000	1,000	1,100	1,200	1,200
25. Black marble	Isle La Motte, Vt	2.682	176.6	1-320	1,000	1,000	1,100	1,200	1,200
26. Sutherland Falls marble	Rutland, Vt	2.666	166.6	1-342	1,000	1,000	1,100	1,200	1,200
27. Conglomerate	Roxbury, Mass	2.708	169.2	1-49	700	800	900	1,000	1,000
28. Potomac stone	Point of Rocks, Md	2.724	170.2	1-60	600	700	800	900	900
29. Conglomerate	Caps a La Aisle, P. Q	2.645	165.3	1-80	600	700	800	900	900
30. Artificial stone	McMurtire and Chamberlain Patent	2.235	139.7	1-280	750	800	1,100	1,200	

*From Notes on Building Stones, by Dr. Hiram Cutting, Montpelier, Vt., 1880. Published also in state reports and Osgoods' Architects, Boston.

of calcination, marbles and limestones withstand heat better than either sandstones or granites.* This result, however, is only partially sustained by Winchell's experiments on the Minnesota dolomites and dolomitic limestones.†

The experience of the citizens of North Arkansas is that marble is much superior to the sandstone in withstanding heat, and because of this fact, where chimneys are built of sandstone the fireplaces are lined with marble.

Crushing test.—The resistance to crushing has more of an indirect than a direct value, for rarely is a building stone loaded to one twentieth of its crushing strength.‡ In such structures as the Washington Monument and the East River bridge piers, the strength of the stone is of vital importance. The power with which it resists crushing is in a fair measure indicative of the cohesive force of the particles of the stone, and hence its capacity to resist freezing, heating, abrasion, etc. Yet the results must be interpreted in the light of the other tests, and even then it is thought by some that the importance attached to this test is much exaggerated. It is no doubt true that the strength of a stone fresh from the quarry is often widely different from what it is a few years after exposure to the weather. Tensile strength is a vital point with the stone for use in certain positions, as lintels, cornices, arch rocks, etc. Elasticity, a fair idea of which might be gained from the resonance|| of the stone, is significant of its durability.

Direct observations.—Prof. Henry says: "The commission§

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*Notes on Building Stones, by Hiram Cutting, State Geologist, Montpelier, Vermont, 1880, p. 10.

†Geology of Minnesota, Vol. I., p. 201.

‡With some builders the limit is one tenth, with others one twentieth, but rarely in ordinary structures does it ever reach even this. The maximum pressure in the Washington Monument, the highest stone structure in the world, is 22.658 tons per square foot. Tenth Census, Vol. X., p. 359.

||Mr. Johnson, after experimenting on the transverse strength and elasticity of rocks, says: "As nearly as the ear could estimate it, the resonance of each piece tested was proportional to the modulus of elasticity as found by the test." Geological Survey of Indiana, 1881, p. 38.

§The commission consisted of General Totten and Professors Bache and Henry, who were appointed by the President of the United States in 1854 to examine the marbles offered for the extension of the United States Capitol.

are convinced that the only entirely reliable means of ascertaining the comparative capability of marble to resist the weather, is to study the actual effects of the atmosphere upon it as exhibited in buildings which for years have been exposed to these influences."* While this is undoubtedly the best means of determining the durability of stones, in America it is impracticable on account of the scarcity of old buildings. Much, however, can often be learned concerning the durability of a stone from an examination of its natural outcrop; but even with the greatest care this is not as trustworthy as the examination of old buildings or a quarry opening of long standing.

Dr. A. A. Julien, from his extended observations on the building and monumental stones in New York City, gives the following rough estimate of the life of each class of stones in that city; signifying by the term *life* "the period after which the incipient decay of the variety becomes sufficiently offensive to the eye to demand repair or renewal":†

Life of building stones in New York.

	Years
Granite	75—200
Gneiss	50 years to many centuries
Coarse brownstone	5—15
Laminated fine brownstone	20—50
Compact fine brownstone	100—200
Limestone, coarse, fossiliferous	20—40
Limestone, fine oölitic (French)	30—40
Marble (dolomite), coarse	40
Marble (dolomite), fine	60—80
Marble, fine	50—200

AIDS FOR PROLONGING THE LIFE OF A BUILDING STONE.

While the durability of a building stone depends largely on its inherent properties and the external agencies which affect it, yet its period of service may often be prolonged many years by taking proper care in dressing, seasoning, and placing in the wall, or by the aid of some liquid preservative.

*Am. Jour. Sci., July, 1856, p. 31.

†Tenth Census, Vol. X., p. 391.

Method of dressing.—The method of dressing has great influence on the durability of a building stone, as a rule a sawed face being more durable than a tool-dressed one, especially if the dressing is done by a heavy axe or hammer. The effect of the hammering is to stun or deaden the surface, that is, to break and loosen the grains, and produce minute fissures, which render the rock susceptible to the action of weathering influences. The following table represents the average results of Mr. Johnson's experiments on sawed and tool-dressed samples of oölitic limestone:*

Strength of sawed and tool-dressed limestone.

	Modulus of rupture.	Modulus of compression.	Modulus of elasticity.
Sawed	2,338	12,675	4,889,480
Tool-dressed	1,477	7,857	2,679,475

It is held by some writers that compact crystalline rocks are most durable with a rock face untouched by chisel or hammer, as "the crystalline facets are best fitted to shed moisture and the natural adhesion of the grains has not been disturbed."†

With the softer and more porous rocks, as limestones and sandstones, it is generally admitted that a smoothly sawed or polished surface is the most durable. Professor James Hall says: "The usual process of dressing limestone rather exaggerates the cause of dilapidation from the shaly seams in the material. The clay being softer than the adjacent stone, the blow of the hammer or other tool breaks the limestone at the margin of the seam, and drives forward into the space little wedge-shaped bits of harder stone. A careful examination of dressed surfaces will often show the limestone along the seam to be fractured with numerous thin wedge-shaped slivers of the stone which have been broken off, and are more or less driven forward into the softer parts. In looking at similar surfaces which have been a long time exposed to the weather, it will be seen that the stone adjacent to the seam presents an interrupted fractured margin; the small fragments having dropped

*Report of the State Geologist of Indiana, 1881, p. 39.

†G. P. Merrill, Smithsonian Report, 1886, Part II., p. 353.

out in the process of weathering. Limestones of this character are much better adapted to rough dressing, when the blows are directed away from the surface instead of against it and when the entire surface shall be left of the natural fresh fracture. By this process the clay seams have not been crushed, nor the limestone margining them broken, and the stone withstands the weather much longer than otherwise."*

All projections such as cornices, sills, lintels, etc., should be throated, that is, undercut in such a way as to throw off dripping water. This principle is maintained by the best architects in England and France, but is commonly neglected in America.†

Seasoning.—Rocks, like timber, should be seasoned before they are used. After removal from the quarry, time sufficient for the moisture or quarry-sap to evaporate, should elapse before they are placed in the wall.‡ While drying they should not be exposed to a hot sun, nor to the freezing of a northern winter; hence in cold climates the stone should be quarried in the spring and summer seasons. If it is to be used for carved work, the carving should be done before the quarry water evaporates and before the rock hardens.

Position in the wall.—The position of the stone in the wall has much to do with its durability.‖ It is agreed that stratified rocks should be placed in the wall with the bedding planes horizontal. That all stones are not so placed is due more to carelessness than ignorance, a carelessness that is often costly. This becomes of vital importance with stones containing shaly seams and partings which are common to many sandstones and limestones. Such stones if placed on

*Report on Building Stones, pp. 27 and 28.

†A. A. Julien, Trans. N. Y. Acad. Sci., January 29, 1883, p. 77.

‡Sir Christopher Wren, it is said, would not accept the stone which he proposed to use in St. Paul's Cathedral, in London, until it had lain for three years, seasoning upon the seashore. Julien, in Trans. N. Y. Acad. Sci., January, 1883.

‖"Improper position in the wall, where it is exposed to the weather, has more to do with the disintegration and decay of building stone, than the chemical composition, and, in many cases, it is more effective than the inherent weakness in its physical structure." J. C. Smock, Bulletin No. 10 of the New York State Museum, 1890.

edge will have soft and hard faces exposed which will weather unevenly and peel off in flakes, rapidly disfiguring and injuring the wall, while if laid horizontal they will last for many years. The denser stones should be used in the bottom layers where constantly exposed to moisture, and if, from necessity, porous stone must be used next to the ground, it should be protected by a coat of some non-absorbent and have a layer of water-proof material, such as asphalt, interposed between it and the superstructure.*

Protecting the stone by means of solutions.—Paint is sometimes used, but is objectionable because it hides the natural beauty of the stone and needs frequent renewal.†

Oil used to protect building stone is estimated to last four or five years; but it discolors the light-colored stones and makes the dark ones darker.

Coal-tar and asphalt are used in protecting foundations from moisture.

Paraffine has been used in different ways with varying success. One method is to dissolve it in coal-tar naptha and apply warm, but this discolors the stone and peels off like paint. Another method is to put the melted paraffine on the stone and heat the surface of the rock to deepen the penetration, but it is thought that the heating of the stone is more injurious than the paraffine is beneficial.

A soft soap and alum solution has been used with a fair measure of success, but requires renewal every three or four years.‡

Several processes, known as Ransome's, Kuhlman's, Szerelmey's, and M. Lewin's, consist either in the application of water-glass (a silicate of potash or soda) alone or along with some other salt, as calcium chloride, aluminum sulphate, or some bituminous substance.

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*Smithsonian Report, 1886, Part II., p. 352.

†Dr. A. A. Julien, Tenth Census Report, Vol X., p. 389, says paint lasts hardly three years in New York.

‡Tenth Census, Vol. X., p. 390.

Other solutions such as beeswax, resin, and coal-tar, have been used with indifferent success.*

The application of any preservative to a building stone is necessarily expensive, but is often less so than a renewal of the stone work. The foregoing are a few of the more common methods employed. The perfect preservative, which preserves without disfiguring the natural beauty of the stone and is inexpensive in application, remains yet to be discovered.

THE COLOR OF BUILDING STONES.

While not of such vital importance as durability, color should not be overlooked in selecting a building stone, especially in large cities, as the beauty of a street or a city depends to a great extent upon the colors of the buildings. High buildings, on narrow streets, built of dull brown stone, or of any very dark colored material, impart an appearance of gloom; while white is too glaring in the sunlight; warm light colored stone with a judicious variation is the most pleasing. It is said that the famous architect Richardson owed much of his success to his skill in selecting stone of such colors as would be the most effective and harmonious in the completed structure.

THE WORKABILITY OF BUILDING STONE.

Other things being equal, that stone is the most desirable which can be most easily wrought into the desired shape. A stone which cuts easily is always desirable for carved work, while flinty, friable, and plucky† stones are avoided as far as possible. However, some of the so-called plucky stones are very durable, and, outside of the difficulty of dressing, are desirable building stones. The ease with which they can be quarried is often an important point in regard to building stones.

*Stones for Building and Decoration, p. 402.

†Plucky is a term used by stone-cutters to designate stones which under the chisel break away in irregular conchoidal chips, and are therefore difficult to trim to a line or bring to a perfect surface.

THE COST OF BUILDING STONE.

The principal items affecting the cost of building stones are abundance, proximity of quarries to places of use, the ease with which they can be worked, the facilities of transportation, and their uses. These differ widely in individual cases.

COMPARATIVE USE OF LIMESTONE FOR BUILDING.

The chief objection to limestone for building purposes is that it is more susceptible to injury from acid-laden atmosphere than other stones. This objection applies more particularly to manufacturing cities where large quantities of bituminous coal are used. It is noteworthy, however, that its use both in public and private buildings is rapidly on the increase. In 1883 Dr. A. A. Julien stated before the New York Academy of Science* that, of the buildings in New York City, 11.6 per cent. were stone, 0.1 per cent. of the stone buildings being of bluestone and limestone, 7.9 per cent. of marble, and 78.6 per cent. of brown sandstone. The low percentage of limestone buildings in New York is due in large measure to the fact that no quarries of good limestone for building purposes were accessible, while the sandstone quarries were convenient; the sandstone was considered fashionable also. In Chicago, Indianapolis, St. Louis, and other cities in the Mississippi Valley where good limestone is accessible, the proportion of limestone buildings to those of other stone is much higher than in New York.

Because of its superior transverse strength, elasticity, the ease with which it can be cut aud carved, and the pleasing contrast in color, limestone is used extensively in trimming brick buildings.

LIMESTONE FOR ROAD-PAVING MATERIAL.

For paving-blocks limestone has little value, as it will not stand the wear of heavy vehicles.† It has been used for

*Trans. N. Y. Acad. Sci., January 29, 1883, p. 67.

†Hard Argentine limestone was tried in Kansas City on a concrete foundation, but, being set on edge it wore unevenly, and in a year or two was split by the frost and had to be replaced by granite and limestone. This is the universal experience of all cities using limestone blocks. Engineering and Building Record, New York, XV., p. 375.

macadamizing, but its sole recommendation appears to be cheapness, as in a limestone region in the absence of other rocks it is used from necessity. The objection is that it will not stand the wear, because it is soon worn into ruts and covered with dust, which in dry weather becomes stifling and in wet weather a disagreeable mud.* It forms, however, an excellent bottom for macadamizing roads if sufficiently covered with gravel or other material to protect it from the wheels.

Gillespie says† that the Carboniferous and older limestones are adapted to road-making, but that those of more recent age are not so well suited for that purpose.

Limestone is used extensively for side-walks, curbing, and sewer caps, for which uses it is well adapted.

The Eleventh Census gives the total amount of limestone used for street work in 1889, as 46,491,622 cubic feet, valued at $2,383,456, of which Arkansas furnished 2000 cubic feet, valued at $500.

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*Omaha, Nebraska, paved its first street with a Telford pavement, twelve inches deep of Nebraska limestone which soon wore into ruts and became covered with mud. Engineering and Building Record, N. Y., XVI., p. 236.

†A Manual of the Principles and Practice of Road-Making, N. Y., 1847, p. 197.

CHAPTER VI.

Miscellaneous Uses of Limestone.

Lithographing.—A good lithographic stone is one of the rarest and most valuable varieties of limestone. It is more or less impure, fine-grained, homogeneous, generally of a yellowish gray or drab color, and has a conchoidal fracture. It must be porous enough to absorb ink, soft enough to work readily under the engraver's tool, and hard enough to stand the necessary pressure put upon it by the printing press. The best and perhaps the only first-class lithographic stone comes from Solenhofen, Bavaria. As this sells in the market for 22 cents per pound* there is a great incentive to find it in America, where it has been diligently sought. Merrill gives the following places as reporting so-called lithographic stone: Talladega county, Alabama; Lawrence county, Indiana; Jones and Van Buren counties, Iowa; Hardin, Estill, Kenton, Clinton, Rowan, and Wayne counties, Kentucky; Ralls county, Missouri; Clay and Overton counties, Tennessee; and Burnett county, Texas.† To these might be added Marion, Izard, and Searcy counties, Arkansas. Whether stone from any of these places will ever replace the Solenhofen stone remains to be seen. Mr. Day says:‡ "The best lithographic stone tested and examined by lithographers during 1888, was taken from a bed in Clay and Overton counties, Tennessee. A number of lithographers have subjected samples of this stone to practical tests, and as a result of their experience express themselves as highly pleased with it, and in one case it was pronounced superior to any German stone previously used by them." Such statements, however, must not be interpreted too literally. The same promising state-

*Mineral Resources of the United States, 1886, p. 690.

†Stone, Indianapolis, Vol. III., p. 101.

‡Mineral Resources of the United States, 1886, p. 690.

ment was made concerning the Lafferty Creek quarry, in Izard county, Arkansas, yet the sample which answered the tests was obtained at a cost of several hundred dollars, and no more of the same quality has since been found. The quarry now stands idle, although it is reported that the sum of $10,000 has been invested in it.

The Eleventh Census (Bulletin 166) gives the total amount of lithographic limestones produced in the United States for ten years as 108 short tons, valued at $1943.

Analyses of lithographic limestones.

	I.	II.	III.	IV.	V.
	Solenhofen		Overton	Ralls	Lafferty.
	Bavaria.		co., Tenn.	co., Mo.	Creek, Ark.
Carbonate of lime	81.47	96.24	77.62	81.77	98.67
Carbonate of magnesia	13.83	0.21	17.32	15.10	2.14
Silica........................	4.45	....	4.10	3.12	0.34
Oxides of iron and alumina ...	0.25	2.02	0.66	0.01	0.07

I. Merrill, Stone, August, 1890. II. Prestwich's Geology, Vol. I., p. 30. III. and IV., Merrill, Stone, August, 1890. V. Geological Survey of Arkansas.

Furnace flux.—As a furnace flux for reducing the iron ores to a metallic state, limestone has an extensive use. For this purpose, while the purer forms are preferable, impure ones, providing the impurities are not injurious, are commonly used on the score of economy. Magnesian limestone is even preferred in many cases, as it is said to remove phosphorus to a certain extent. The following table by Hartman* shows the relative value of different limestones depending on the percentage of silica, lime, and magnesia:

*Mineral Resources of the United States for 1883 and 1884, p. 670. First published in the Bulletin of American Iron and Steel Association. The basis of the calculation is magnesian limestone at 56 cents per ton, and fuel at $3.50 per ton, both at the furnace.

Relative value of limestone as flux.

Limestone.			Magnesian limestone.							
Silica.	Lime.	Value.	Silica.	Lime.	Magnesia.	Value.	Silica.	Lime.	Magnesia.	Value.
P. ct.	P. ct.	Cents.	P. ct.	P. ct.	P. ct.	Cents.	P. ct.	P. ct.	P. ct.	Cents.
0	55	57	0	37	16	64	8	37	11	40
1	54	54	1	37	16	61	10	36	11	34
2	53	51	2	36	16	58	12	35	10	29
3	52	48	4	35	16	53	13	35	10	26
4	51	45	6	34	15	48	14	34	10	23
5	50	42	8	33	15	42	15	34	10	20
6	50	39	10	32	15	36	0	45	8	59
7	49	36	12	31	14	31	1	45	8	56
8	49	33	13	31	14	28	2	44	8	53
9	48	30	14	30	14	25	4	43	8	48
10	48	27	15	30	14	22	6	42	7	42
11	47	25	0	41	12	61	8	41	7	37
12	47	23	1	41	12	58	10	40	7	31
13	46	20	2	40	12	56	12	39	6	26
14	46	17	4	39	12	50	13	39	6	23
15	45	14	6	38	11	45	14	38	6	20
....	....	....	....	....	....	....	15	38	6	17

From this it seems that up to a certain limit the value of a limestone as a flux increases as the per cent. of magnesia increases and as the per cent. of silica decreases. The more siliceous the ores are, the more limestone is needed. An excess of limestone, while requiring more fuel, is said to purify the iron from sulphur, and, owing to its cooling action, to prevent the reduction of silica to silicon.*

Greater care is now being exercised in the selection and use of lime as a flux since the slag, formerly a waste product, is being utilized in so many ways. It has been estimated that the slag of Great Britian amounts to 8,000,000 tons annually. As this means nearly a like amount of limestone used, it can readily be seen that it is no small industry. The serious question involved in getting rid of this waste matter has instigated practical scientific men to seek means of utilizing it, and now as a result in many places it is used in making cement, sand, bricks, glass, railway sleepers, paving material, etc. For most of these uses a slag of approximately uniform composition is required, which necessitates homogeneous limestone and a careful charging of the furnace. In Arkansas the limestone

*Mineral Resources of the United States, 1883 and 1884, p. 670.

of the Boone chert series and the Izard limestone are well suited for flux, as are some of the dolomites.

The limestone is sometimes burnt to a lime before it is put in the furnace, but it is generally used in its crude form, the burning being done in the furnace.

At Ougrée, Belgium, in 1849, experiments to find the relative value of lime and limestone as a furnace flux, showed that there was a saving of 10 per cent. in using the burnt lime.*

Production of limestone for iron flux in the United States, 1880–1889.†

Year.	Long tons.	Value.
1880	4,500,000	$ 3,800,000
1881	6,000,000	4,100,000
1882	3,850,000	2,310,000
1883	3,814,273	1,907,136
1884	3,401,930	1,700,965
1885	3,356,956	1,678,478
1886	4,717,163	2,830,297
1887	5,377,000	3,226,200
1888	5,438,000	2,719,000
1889	6,318,000	3,159,000
Total	46,773,322	$27,431,076

Glass manufacture.—The use of lime as a glass-making material is said by Joseph D. Weeks to be of comparatively recent date; though it is found in ancient glass, according to this writer it entered as an impurity with soda or potash and not by intent. However, its value and importance in glass manufacture today is unquestioned. It enters into the composition of nearly all varieties of glass except flint or crystal glass. Glass is essentially a silicate of potash or soda and a heavier base, such as lime, alumina, or lead, which are the more common ones used. Lime hardens the glass, alumina renders it less fusible, and lead more brilliant. Glass is more or less soluble, a defect which lime tends to remedy. Mr. Weeks says:‡ "Glass rich in lime requires a higher tempera-

*The Mining Magazine, New York, 1853, Vol. I., p. 319.

†Eleventh Census, Bulletin No. 166.

‡Mineral Resources of the United States, 1883 and 1884, p. 968.

ture to melt, and because of this is more destructive to the pots, but used in proper proportions it promotes the fusion, and aids in the decomposition of the materials and improves the quality of the glass. Lime glass cannot compete with lead glass in brilliancy; but it is harder, not so easily scratched, holds its polish longer, is more elastic and consequently tougher, will stand higher temperatures, resists the action of water and chemical agents, and is very much more cheaply produced. Lime glass is also, because of the little difference in the specific gravity of the two silicates of which it is composed, less liable to become striated. In the manufacture of plate glass, which is ground and polished, it is found that glass which is rich in lime is harder to polish than that which is poor in lime, but it holds its polish better and longer. In a word, glass which is rich in lime is to be preferred by the consumer, but not by the producer. It has been asserted that lime glass is more liable than other glass to devitrify or to lose its vitreous, glassy structure, and become crystalline. It is probable that devitrification is the result of using an excess of lime and is not due to the use of lime itself, as the same phenomena are observed when an excess of sand or lead is used."

Both limestone and caustic lime are used, and, like all other glass-making materials, should be as free from impurities as possible. The following analyses show the composition of two limestones largely used in Pittsburgh glass works. No. 1 is largely used by the window-glass manufacturers, and No. 2, by the lime-flint glass manufacturers.*

*Mineral Resources of the United States, 1883 and 1884, p. 969.

Analyses of limestone used in glass-making.

	No. 1. From Blair county, Penn. Per cent.	No. 2. From Sandusky, Ohio. Per cent.
Hydroscopic moisture	......	.40
Organic matter	.09	.05
Silica	1.01	1.00
Peroxide of iron	......	.12
Carbonate of iron	.165	......
Alumina	.02	.40
Carbonate of magnesia	1.48	41.43
Carbonate of lime	97.23	56.60
Total	99.995	100.00

Professor Orton says:* "A large part of the plate-glass manufacturers of Pittsburg draw upon the Niagara limestones of Ohio (which are the purest limestones of the state) for their lime supply, and the new factories of Ohio and Indiana use these stones almost exclusively."

In 1883 the annual consumption of limestone in the glass works of the United States was estimated at† 3500 tons, and that of lime, 900,000 to 1,000,000 bushels.

Carbonic acid gas.—It is estimated‡ that in 1883 there were 25,000 tons of marble dust used for the generation of carbonic acid gas in soda fountains, and the quantity now used is probably much larger. This is mostly made from the scrap marble of the quarry and mill. Marble is used because it is a purer form of lime carbonate and is more easily ground than the ordinary compact limestones.

Other uses of lime carbonate.—Limestone is used in the manufacture of other lime salts and in the production of carbonic acid gas for laboratory operations. The Eleventh Census reports 150 cubic feet of a highly siliceous variety from Kentucky, valued at $500, which is used for polishing marble, gold, and silver. Chalk is made into common whiting,

*Tenth Annual Report of Ohio Society Surveyors and Civil Engineers, 1889, p. 98.

†Mineral Resources of the United States, 1883 and 1884, p. 970.

‡Mineral Resources of the United States, 1883, p. 464.

Spanish whiting, gilders' whiting, Paris white, and prepared chalk drops. The whiting is used principally for calcimine, but is also employed in the manufacture of putty, rubber, oil-cloth, wall-papers, and fancy glazed papers. All the chalk used in this country is imported, while great beds of it lie undeveloped in Arkansas. The imports of whiting and Paris white in 1867 amounted to 8,168,123 pounds valued at $40,879 and in 1887, 1,248,142 pounds valued at $4,657.*

USES OF LIMESTONE AS QUICKLIME.

Lime (CaO)—(synonyms quicklime, caustic lime, lime oxide)—is the most important of all building materials as it is practically indispensable in masonry construction of every kind.

For commercial purposes it is obtained by expelling the carbonic acid in the form of a gas from common limestone by means of heat.†

Varieties of lime.—As already described (p. 40) limestone, while consisting essentially of carbonate of lime, rarely if ever occurs pure, and as the limestone varies in composition, so will the lime obtained from it. The innumerable varieties are grouped for commercial purposes into classes. Gillmore‡ divides all natural and artificial products suitable for mortar into five classes: (1) common or fat limes; (2) poor or meagre limes; (3) hydraulic limes; (4) hydraulic cements; (5) natural pozzuolanas.

The *common, fat, or rich* limes usually contain less than 10 per cent. of impurities. With the exception of some of the impurities they are entirely soluble in water, and will not harden under water. In slaking they increase in volume from two to three and a half times the original mass. In hardening they shrink so that they cannot be used without a large dose of sand. They are cheaper and more general in their use than the other varieties.

The *poor or meagre* limes contain impurities from 10 to 25

*Mineral Resources 1887 p. 677.

†The reaction is $\underset{\text{(limestone)}}{CaCO_3}$ heated $= \underset{\text{(lime)}}{CaO} + \underset{\text{(carbonic acid gas)}}{CO_2}$.

‡On Limes, Hydraulic Cements, and Mortars, p. 69.

per cent., sometimes as high as 39 per cent. of the whole, and are less desirable for mortars than the preceding.

The *hydraulic* limes are divided into three classes: (1) limes slightly hydraulic, in which the impurities form 10 to 20 per cent. of the whole; (2) hydraulic limes, in which the impurities range from 17 to 24 per cent.; and (3) limes eminently hydraulic, containing from 20 to 35 per cent. All of them possess the property of hardening under water.

Hydraulic cement, which is an artificial product, contains a lower percentage of lime than any of the others, although rarely falling below 29 per cent. of the whole. A good grade of English Portland cement contains 37.86 per cent. of silica, alumina, magnesia, and alkalies. Analysis of the French Boulogne Portland cement shows 34.87 per cent. of impurities. For analyses, see Chapter VIII.

The *natural pozzuolanas* are volcanic or igneous rocks which possess hydraulic properties, and rarely contain more than 10 per cent. of lime. They are not known to occur in the United States.

Professor Orton,* State Geologist of Ohio, says the limes of that state are divided in the markets into four groups as follows:

1.	Carbonate of lime	55 per cent.	Carbonate of magnesia	43 per cent.
2.	" " "	65 " "	" " "	30 " "
3.	" " "	75 " "	" " "	20 " "
4.	" " "	85-95 " "	" " "	2-10 " "

Selection of lime.—The selection of lime is greatly governed by custom. The Romans, noted for the excellence of their masonry, preferred, according to Pliny, the rich limes. That author says:† "The censor disparages lime made from variegated stones. That made from white is better. That obtained from hard stone is better for building purposes, that from porous is better for plastering. The lime is better when the stone is dug out of the ground, rather than

*Tenth Annual Report of Ohio Society of Surveyors and Civil Engineers, 1889, p. 95.

†Historia Naturalis, 36, 23, 55.

collected on the banks of rivers." In the United States the majority of builders favor a pure ("fat") lime, and it is commonly valued according to its purity; English builders and some Americans prefer a lime with a considerable percentage of magnesia (a "meagre lime"). The rich lime takes a larger dose of sand and hence makes more mortar, but it is claimed by some that the magnesian limes are more permanent.* For hydraulic purposes the cement is preferable to hydraulic lime, and in nearly all cases is so used.

Slaking the lime.—The slaking is accompanied by an evolution of heat and an increase of volume, both increasing with the purity of the lime. A fat lime in slaking soon raises the water to the boiling point. It has been known to start a conflagration from an accidental wetting while under transportation.†

The meagre and hydraulic limes slake slowly with little increase of temperature or volume. Hydraulic cements are not slaked, but after burning are ground and packed in barrels or sacks ready for use.‡

There are three methods of slaking lime: air-slaking, immersing, and drowning.

Air-slaking is a method which is avoided as far as possible in the manufacture of mortar; but as lime begins to slake as soon as exposed to the atmosphere, it can be wholly avoided only by using fresh lime. The power of lime to resist air-slaking depends upon its composition, the humidity of the atmosphere, and the means taken to protect it from the air.

Slaking by immersion consists in placing lime broken into pieces about the size of a walnut in a wire basket and immersing them for one or two minutes, after which they are withdrawn before reduction begins; they are then packed in heaps

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*Tenth Annual Report of Ohio Society of Surveyors and Civil Engineers, 1889, p. 97.

†Pliny in noting this property says: "Lime is set on fire by water as is the Thracian stone, which is put out by oil. The fire is especially fierce in the presence of vinegar, bird-lime, and eggs." Historia Naturalis, 33, 5, 30.

‡For process of manufacture, see An. Rep. of the Geol. Survey of Arkansas for 1888, Vol. II., p. 291.

in casks or bins and covered to retain the heat and moisture, when the lime is reduced to a fine powder. It is sometimes covered with sand and left several months. The objection to this process is its cost, but a modification of it, which consists in sprinkling the broken pieces, is sometimes used.

The *drowning* process consists in putting on the lime enough water to convert it all into a thick pulp, and is the one generally used in this country. This process is conducted in a water-tight box and it is necessary to add at first only the required amount of water. The effect of adding too much water is to reduce it to a semi-fluid condition, thus injuring its binding properties; if more water is added after the process is begun, the temperature is lowered, the lime chilled, and the product rendered granular and lumpy. It is customary in some places to add hot water as an aid in hastening the process.

Setting.—The lime after slaking is mixed with a certain quantity of sand, the quantity depending upon the quality of the lime, and thus forms mortar. The mortar sets, that is, solidifies in drying, thus binding the separate stones or bricks into a solid mass. In the slaking process the lime, or calcium oxide (CaO), combines with the water (H_2O), forming the hydroxide ($Ca2HO$) known as slaked lime. The further changes in the setting or hardening of the mortar has been the subject of much discussion. Q. A. Gillmore, of the U. S. Corps of Engineers, who is an excellent authority on the subject, says: "To the chemical formation of silicate of lime and carbonate of lime, and the crystallization of the hydrate between and upon the surfaces of the sand, we must ascribe the solidification of common mortars."* Nearly all the lime finally changes into the carbonate, the absorption of carbonic acid continuing for many years. Mortar should not be disturbed in the drying process, and should not dry too rapidly. It is the custom with some masons to dampen the wall in dry weather that the mortar may set more firmly.

The uses of sand, so far as known, are: to furnish points

*On Limes, Hydraulic Cements, and Mortars, p. 299.

upon which the lime may crystallize; to prevent contraction and cracking, as a pure lime mortar in drying contracts greatly, causing numerous cracks; to produce a chemical action between the lime and sand, thus forming the silicate of lime; and to cheapen the mortar by increasing its bulk. Professor Orton suggests that a further use of the sand is to render the mass porous, so that the carbonic acid in the air may penetrate to the interior of the mass.*

In cement the setting consists in the hydration, that is, the chemical union of the silicates and aluminates of lime with water, and is a much shorter process than the setting of ordinary mortar. Some of the quick-setting cements harden in three or four minutes, while others take as many days, the time depending on the quality. The use of sand in the cement is simply for economy, as it increases the bulk at little cost. The quantity of sand which can be mixed with the cement without injury depends on the quality of the cement and the purposes for which it is to be used. In special cases it is used without sand.

The common lime is used in ordinary building more extensively than cement, on the score of economy, as it is more abundant, is more easily burnt, gives increased volume in slaking, takes a larger dose of sand, and is, therefore, cheaper. The cement is used in all masonry under water, and, on account of its superior qualities, is coming more into use in superstructures. It is being put to many new uses and the demand for it is constantly increasing.

Lime as a fertilizer.—Lime is used as a fertilizer almost universally in some localities, while in others it is condemned. Thus in parts of Pennsylvania and New York it is used in large quantities,† while in eastern Massachusetts, according to Professor Storer, it is rarely if ever used. So strong is the

*Tenth Annual Report of the Ohio Society of Surveyors and Civil Engineers, 1889, p. 104.

†It was customary a few years ago for the farmers in central Pennsylvania in the coal regions on the west side of the mountains to haul coal across to the east side and trade it for lime to put on their land.

prejudice against it in some places that landlords forbid the tenants by contract from using it on the soil. The opposition to its use is due in most cases to ignorance of its properties, and hence its abuse, for while one of the most useful fertilizers, if used intelligently, it is subject from its nature and action to greater abuse than any other.

The advantages of lime may be summed up as follows:

1. It is an essential constituent of fertile soil, as it is found in all cultivated plants, occurring in some in small quantities, in others forming a considerable part. The following, according to Professor John Wrightson, are the plants richest in lime:

"*Percentage of lime in the ash of certain cultivated plants.*"

Potatoes, stem and leaves	46.2 per cent.
Tobacco	67.44 " "
Red clover	39.7 " "
White clover	32.2 " "

"Experiment has demonstrated that lime is absolutely necessary to the development of all plants, and the above list shows how largely it is appropriated by them."

It is sometimes the case that a sandy or clayey soil is practically barren of lime, but so abundantly is it distributed that soils not having sufficient lime for the needs of plants are indeed rare.

2. By reason of its strong basic action it attacks and decomposes insoluble silicates, so that essential elements, such as potash, ammonia, and magnesia, which would otherwise be in a locked-up condition, are rendered soluble and thus available for the use of the plant. The sudden increased fertility produced by liming waste land is generally due to this action. This is especially true of feldspars and soils derived from them. Experiments are reported* which show that lime not only attacks feldspar, but acts on quartz as well, with which it produces a hydrated silicate of lime easily soluble in acids. However, it is stated that gypsum, the sulphate of lime, will answer this purpose equally well.

*Storer, Agriculture in its Relations with Chemistry, p. 150.

3. It promotes and quickens the decay of vegetable matter, converting it into true humus, to which is generally due the black color in soils, a fact which the observing farmer is quick to recognize. It serves to decompose the inert nitrogen compounds of humus, and is thus valuable on peat or bog land. It is urged by some writers that lime or lime carbonate promotes the formation of nitrates within the soil. A familiar fact in proof of this is that nitrates are apt to form in limestone caves. Recent experiments* show that lime carbonate is a great aid, if not essential, to nitrifying fermentation.

4. Soils rich in lime stand wet weather or drouth better than a corresponding soil poor in lime.

5. It makes the land more friable and hence more easily cultivated. It keeps clay land from baking, and on sandy land prevents the crops from burning. Some clayey soils which from their composition ought to produce well, are remarkably barren, a fact thought to be due to the baking of the clay into stone-like clods, a fault which lime tends to remedy.

6. It corrects the acidity of the soil common in wet places. A coating of lime will change a growth of sour grass to a more succulent and nutritive one.

7. Lime destroys insects, worms, and fungi. It has been used to destroy the rust or smut of seed-grain, to check the "finger-and-toe" disease and the "club-foot" in turnips.

The abuse of lime lies in using it for its stimulating properties alone, for by its continued use, without the addition of other fertilizers, as barn-yard manure or guano, it is possible to practically exhaust the soil of its fertility.† Lime cannot be used as a substitute for other fertilizers, for it does not contain all the ingredients of plant life. Its universal use is not to be commended, as many soils do not require it, but it is specially advantageous to clayey, boggy, sandy, and sour soils, and can be used along with other fertilizers advantageously in most soils.

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*Storer, Agriculture in its Relations with Chemistry, p. 150.

†The adage that "lime enriches the father but impoverishes the son" is due to its abuse.

Limestones or marls can be used as a substitute for lime where the caustic property is not desirable, and they are not subject to the abuse of quicklime. They are less active than lime, hence are more lasting, and marl frequently has an additional value from other elements contained in it. Whether the use of carbonate of lime in the pulverulent state is economical depends on how cheap it may be obtained in that form. In the northern part of Arkansas, where the limestones are all so compact, it would be cheaper to burn it and put it on as quicklime, but in the southern part of the state, in the vicinity of the great chalk beds, it would be more economical to add the chalk without burning.

Other uses of lime.—Lime is used in large quantities for plastering and whitewashing, for which purposes the pure, or at least white lime, is preferred. It is largely used as a disinfectant, both as the oxide and the chloride. The chloride is also used for bleaching. Tanning and glass-making require large quantities of lime.* In chemical operations it is used for drying gases and liquids, in the preparation of the caustic alkalies, in the liberation of ammonia, in the manufacture of soda by the Le Blanc process, and in the analysis of organic compounds containing chlorine, bromine, and iodine. Lime-water is used as a chemical reagent in the laboratory and is also used in pharmacy. Lime has a further use in the lime light (calcium light or oxy-hydrogen light) where its incandescent and incombustible properties make it valuable. It may be used as a mold for casting iron or steel. It is likewise a highly refractory material and is used to make crucibles for fusing certain refractory substances.

The production of lime in the United States from 1880 to 1889.†

Year.	Barrels.	Value.	Year.	Barrels.	Value.
1880	28,000,000	$ 19,000,000	1886	42,500,000	$ 21,250,000
1881	30,000,000	20,000,000	1887	46,750,000	23,375,000
1882	31,000,000	21,700,000	1888	49,087,000	24,543,500
1883	32,000,000	19,200,000	1889	68,474,668	33,217,015
1884	37,000,000	18,500,000			
1885	40,000,000	20,000,000	Totals for 10 years	404,811,668	$220,785,515

†Eleventh Census, Bulletin No. 166.

*See p. 79.

*Lime and cement of domestic production exported from the United States, 1864 to 1890.**

Years.†	Quantity.	Value.	Years.†	Quantity.	Value.
	Barrels.			Barrels.	
1864		$86,386	1880	41,989	$ 52,584
1865		94,606	1881	57,555	83,598
1870	31,175	61,490	1882	67,030	100,169
1871	27,575	51,585	1883	74,687	120,156
1872	39,686	69,218	1884	65,768	108,437
1873	27,873	52,848	1885	79,627	127,523
1874	41,349	69,060	1886	83,247	123,687
1875	64,087	98,630	1887	63,520	97,771
1876	53,827	77,568	1888	100,070	147,309
1877	78,341	97,923	1889	89,925	142,298
1878	82,507	98,334	1890	86,963	152,295
1879	60,657	74,097			

General statistics of limestone production in 1889.‡

States and Territories.	Total value of product.	Total wages.	Total expenses.	Total capital.
Total	$19,095,179‖	$10,121,985	$15,092,714	$27,022,325
Alabama	$ 324,814	$ 199,480	$ 259,118	$ 353,071
Arkansas	18,360	9,850	14,440	32,531
California	516,780	164,615	354,930	857,409
Colorado	138,091	73,960	94,064	183,370
Connecticut	131,697	43,186	108,048	100,465
Idaho	28,545	11,159	17,301	27,200
Illinois	2,190,607	1,247,097	1,707,938	3,316,616
Indiana	1,889,336	1,025,689	1,423,504	3,170,385
Iowa	530,863	329,442	432,465	1,008,992
Kansas	478,822	317,480	364,049	734,301
Kentucky	303,314	194,092	240,744	510,189
Maine	1,523,499	679,825	1,474,890	1,120,500
Maryland	164,860	69,980	138,703	418,168
Massachusetts	119,978	47,431	95,831	72,451
Michigan	85,952	44,211	58,132	184,318
Minnesota	613,247	367,321	497,498	1,186,847
Missouri	1,859,960	1,181,115	1,523,257	2,066,017
Montana	24,964	16,375	20,350	39,500
Nebraska	207,019	129,906	164,533	268,710
New Jersey	129,662	62,926	109,492	152,539
New Mexico	3,862	1,754	3,019	19,600
New York	1,708,830	846,623	1,268,151	2,664,847
Ohio	1,514,934	797,082	1,138,070	2,283,966
Pennsylvania	2,655,477	1,421,496	2,178,013	3,402,345
Rhode Island	27,625	9,992	22,440	37,400
South Carolina	14,520	8,555	11,440	14,250
Tennessee	73,028	38,040	51,487	79,915
Texas	217,835	96,778	114,022	69,705
Utah	27,568	13,172	19,577	155,225
Vermont	195,066	55,959	141,660	160,424
Virginia	159,023	80,994	116,636	99,875
Washington	231,287	133,215	211,418	584,825
West Virginia	93,856	28,651	51,323	217,188
Wisconsin	813,963	345,184	617,911	1,397,986
Other states§	77,935	29,350	48,260	31,175

*Mineral Resources U. S., 1889-90, p. 462. The cement imported into the United States in 1890 is given as 1,940,186 barrels, valued at $2,249,741.

†Calendar years ending December 31, from 1886 to 1890; previous years end June 30.

‡Eleventh census, Bulletin No. 78.

‖This, it is stated, represents only the product from the regular limestone quarries.

§The states here grouped, in order that the business of individual establishments may not be disclosed to the public, embrace Arizona, Florida, Georgia, Oregon, South Dakota, and Wyoming.

CHAPTER VII.

THE CARBONIFEROUS LIMESTONES OF NORTH ARKANSAS.

In North Arkansas there are not less than seven distinct limestone formations: the Pentremital, Upper Archimedes, gray limestone, and St. Joe marble of the Boone chert series, all in the Lower Carboniferous; and the St. Clair marble, Izard limestone, and magnesian limestones of the Lower Silurian age. Besides these formations, which occur over large areas, are others more local in their extent, such as the Kessler limestone in Washington county; limestone in the Fayetteville shale in Independence county; a bituminous lenticular limestone immediately underneath the Batesville sandstone; a blue limestone associated with the magnesian limestones; and different beds of the magnesian and siliceous limestones in the Silurian. The position of the different beds relative to other formations and the maximum thickness of each are shown in the general section on page 10.

The maximum thickness of all the different limestone beds exclusive of the lower ones of the magnesian limestones of the Silurian is over 1000 feet, and, distributed as they are from the top to the bottom of the exposed rocks, alternating with beds of sandstone, shale, and chert, limestone of some kind is brought within convenient reach at every point in the northern part of the state.

THE PENTREMITAL LIMESTONE.

The Pentremital limestone forms a prominent bed in Washington county, where Professor Simonds says it reaches a thickness of ninety feet.* It also occurs in Madison county and probably in the counties further east and south, where it was not distinguished from the Archimedes limestone. It is an

*An. Rep. of the Geol. Survey of Arkansas for 1888, Vol. IV., p. 83.

impure, dark-colored, loose-textured, fossiliferous formation of comparatively little economic value. In a region otherwise devoid of limestone it would have a local value for making lime, but in the region where it occurs there are other limestones better adapted to that purpose.*

THE ARCHIMEDES LIMESTONE.

The Archimedes limestone is impure, generally loose-textured, and very fossiliferous, varying from bluish gray to brown in color. In most places it is distinguished by its characteristic fossil, a spiral shaped bryozoan of the genus *Archimedes*, from which it is named.† The compactness of the stone appears to vary with the size of the fossils: when they are large, the texture is open, being often but a loosely aggregated mass; where the fossil fragments are small, they are closely compacted and the rock is firm and durable. In some places the formation graduates into sandstone, the change being so gradual that there is no line of demarcation between the two. In other places it is very argillaceous, and in most places it contains iron and bituminous matter. In some places it has a loose shaly structure, while in others it occurs in strata ten feet or more in thickness.

Thickness.—The Archimedes limestone varies in thickness in different localities from a few inches to eighty feet or more. In Washington county it is from twenty-five to forty feet thick; on Pinnacle Mountain, Newton county, it is eighty feet thick; but it is apparently thicker than that on the face of the Boston Mountains, south of Buffalo River, where no measurement was made. Mr. C. E. Siebenthal, one of the Survey's assistants, reports a thickness of 200 feet in the Boston Mountains, south of Mountain View.‡ Dr. Shumard gives it a

*For further details, see An. Rep. of the Geol. Survey of Arkansas for 1888, Vol. IV., p. 83, *et seq.*

†Figures of Archimedes are given in the An. Rep. of the Geol. Survey of Arkansas for 1888, Vol. IV.

‡This may also include the Pentremital limestone and accompanying shales.

thickness of 200 feet in Eastern Missouri, this thickness including beds of associated marls.*

Geologic position.—The Archimedes limestone is in the Boston group of the Lower Carboniferous rocks (Genevieve of H. S. Williams). It overlies the Marshall shale, from which it is separated in some places by shaly sandstones and shales, and is overlain by shale and sandstone.

Distribution.—The Archimedes limestone is widely distributed over North Arkansas, occurring at nearly all clear rock exposures at the proper horizon, but as it is in some places less durable than the overlying rocks, it is frequently concealed by talus. In some places it is more durable than the overlying rocks and forms a prominent escarpment along the face of the mountains. It outcrops along the north face of the Boston Mountains and in many of the northern outliers from Independence county west into Indian Territory. It outcrops also on the south side of the Boston Mountains in several places in Crawford, Franklin, Johnson, and Newton counties. In Limestone Valley, Franklin county, Assistant J. H. Means found it to have a thickness of 100 feet or more.†

It is prominently developed in the group of mountain peaks in the southern part of Boone county and the northern part of Newton county. It forms the cap rock of Fodder Stack Mountain in a ledge twenty-five feet thick, covering an area of about 100 square feet. From this ledge numerous boulders, some of them many tons in weight, have rolled down the mountain side and form a great mass of talus near the base of the south side. On Pinnacle Mountain it forms a prominent ledge eighty feet thick, 400 feet below the top of the mountain. It is very fossiliferous on the south side of the mountain, containing *Archimedes* nearly a foot in length. On Pilot Mountain, at the north end of Boat Mountain, it is thirty feet thick and lies 200 feet below the top of the mountain.

*Geological Survey of Missouri, 1855, Part II., p. 151.

†See chapter on the Carboniferous Limestones south of the Boston Mountains, by J. H. Means. (Chapter IX.)

It is concealed by talus in many places on both Pilot and Boat Mountains.

There are large exposures of the Archimedes limestone on both sides of Buffalo River, in Newton county, on the mountain between Big and Little Buffaloes, and in many places along the north face of the Boston Mountains through Searcy, Stone, and Independence counties. It forms a prominent outcrop on the mountain south of Jamestown, Independence county; on Salado Creek, in the same county, it occurs in many places, and it skirts the highlands southwest of the Oil Trough bottom.

Uses—In most places the Archimedes limestone is too loose and crumbling for a good building stone. However, in one place, on Salado Creek, Independence county, it occurs as a beautiful compact rock, partly crystalline, semi-oölitic in appearance, is composed of light gray fossiliferous particles, takes a good polish and makes a fair marble. No doubt good building stone could be obtained from this formation at many places.

Mr. C. E. Siebenthal reports a quarry with a face of twenty to twenty-five feet of Archimedes limestone on the property of Mr. Dorman, in 15 N., 31 W., sec. 24, near Prairie Grove, in Washington county. A tombstone made of it is said to have polished nicely, but soon showed signs of decay. The product of the quarry is used almost entirely in Prairie Grove as bases for tombstones.

It can be used for lime burning in the absence of other limestones, but on account of its impurities it is generally inferior to the chert limestones for this purpose.* Where crumbling enough to be easily shattered it would make a good fertilizer without burning.

THE LIMESTONES OF THE BOONE CHERT.

The Boone chert contains large quantities of limestone, some of the most valuable beds in the state occurring therein.

*It has been used for lime in Washington county. An. Rep. of the Geol. Survey of Arkansas for 1888, Vol. IV., p. 129.

In different parts of the region it varies widely both in quantity and quality. In some places the formation is made up almost entirely of limestone, while in others it consists almost entirely of chert. For convenience the subject is divided into three parts: (1) the limestone underlying the chert; (2) the limestone overlying the chert; and (3) the limestone in the chert bed. The bed underlying the chert has been designated the St. Joe marble, and is described in detail in subsequent chapters under that head.

The limestone overlying the chert bed.—The limestone overlying the chert bed is classed and mapped as part of the chert bed, but in many places it is apparently a separate bed, quite distinct from the chert. In most places it has a dark gray color on a fresh fracture, but on exposure the color changes to a light gray, due to the loss of its bituminous matter. In some places the rock is almost entirely free from organic matter. It is coarsely crystalline, slightly fossiliferous, homogeneous in texture, and very tenacious; has a conchoidal fracture, gives out a fetid odor on a fresh surface, and rarely presents sharp edges on weathered exposures, but outcrops in rounded boulders or prominences through the soil. In places the limestone contains numerous small fragments of angular chert, which were apparently scattered through the limestone deposit before the latter had solidified.

The limestone overlying the chert bed was not observed in the eastern part of the area, where, however, limestone does occur in many places near the top of the chert bed, but either contains intercalary chert, or is overlain by thin layers of chert, and is distinct lithologically from the bed overlying the chert in the western part of the area. It occurs in the western part of the state in Carroll, Madison, Benton, and Washington counties, where it outcrops around the numerous outliers of the Boston Mountains. Comparatively small quantities of it are exposed on Grindstone and Pond Mountains, near Eureka Springs, but on Swain Mountain, 19 N., 26 W., it forms a prominent ledge around the east end of the mountain between the chert and the overlying Batesville sand-

stone, outcropping in rounded ledges along the Eureka Springs–Huntsville road, where it is very dark colored, almost black on a fresh surface. It is exposed in large quantities in 19 N., 27 W., on the ridge between the Clifty Creeks and Stanley Branch around the borders of the Batesville sandstone areas. It occurs in heavy ledges around the base of Keefer Mountain, south of Hindsville, in 17 N., 27 W., the largest areal exposure being on the south side of the mountain. It outcrops around the base of Aunt Katy and Means Mountains, west and northwest of Hindsville. It is exposed in places along the border of the Batesville sandstone area as shown on the southern part of the Eureka Springs sheet, large areal exposures occurring about Goshen, in 17 N., 28 W., and on the tributaries of Richland Creek. It also outcrops on Poor, Ellis, Humphrey, Blansett, and other Mountains on the west side of White River.*

But little use has been made of this stone, no doubt because of its occurrence so near better limestones. For local use it has the advantage over other limestones in occurring on the tops of the hills and thus having down grade for transportation. It could be used for making lime and for building purposes, but is not so good for these purposes as some of the limestones at a lower level.

The limestone in the Boone chert.—Though one of the most variable in quantity and quality, the limestone in the Boone chert is one of the largest and most valuable beds in North Arkansas. Instead of a persistent, clearly-defined bed of limestone running through the chert, there is rather a bed of chert with large quantities of limestone variously mixed through it. In some places the limestone is in irregular layers varying from one inch to a foot or more in thickness, intercalated with like irregular layers of chert; in other places the limestone occurs in lenticular masses; again, the chert is in lenticular or nodular masses in the limestone; in still others they are so intimately diffused that it is not possible to draw any sharp

*For further particulars on this region, see the An. Rep. of the Geol. Survey of Arkansas for 1891, Vol. II.

line between them. It often happens, however, that the limestone forms a bed from twenty to 100 feet or more in thickness, almost or entirely free from chert. It is in such places that the stone acquires an economic value.

Nearly all the limestone in the chert is more or less crystalline, but it is much more so in some places than in others. In a general way it is more crystalline in the central part of the area than in either the east or the west, and more crystalline in the eastern part of the area than in the western. While there are many local changes in color, texture, and structure of the limestone in the chert, there are some distinctly marked varieties of it. The oölitic limestone, which is one of the most valuable varieties, is known to occur in three localities: one northeast of Batesville; another near War Eagle Creek, about four miles north of Huntsville; and another on Brush Creek, 17 N., 28 W. The stone at Batesville, which is known throughout the state as Batesville limestone, is harder and more crystalline than that at the other two localities; it is hard enough to take a good polish and has been successfully used for monuments. It occurs in layers from three to five feet thick, comparatively free from seams or flaws, and can be quarried in as large pieces as can be handled. In color and appearance it resembles the Indiana oölitic stone somewhat, but is harder and more crystalline than most of the Indiana stone and will therefore take a finer finish, and for the same reason is harder to work. The stone found at the two other localities mentioned above is lighter colored, softer, and more easily wrought.

Another variety occurring in the western part of Independence county is a hard, compact, close-grained, finely crystalline, slightly fossiliferous, dark colored stone, the dark color being due to bituminous matter, which in some places occurs only in such small quantities as to give the stone a light gray color. In some places it develops a shaly structure, but in most places occurs in layers from two inches to three feet in thickness which are firm, solid, and resonant.

A variety which occurs widely distributed over the central

part of the area is highly fossiliferous, coarsely crystalline, and varies from light to dark gray in color. The fossils are mostly crinoid stems, with numerous bryozoans and brachiopods. In some places it contains considerable amorphous matter, but in many places is almost completely crystalline and makes a good marble which has had a local use for tombstones.

The limestones in the chert vary greatly in composition, ranging by close gradations from chert to almost pure calcium carbonate. However, in nearly all places where the large beds of limestone occur, it is a comparatively pure carbonate of lime. Some nodules or lenticular masses of chert occur in the heavy beds of limestone, but in no instance was there any considerable quantity of silica found diffused through the bed of limestone. The whole series in fact might be divided into (1) chert almost free from lime, (2) calcareous chert or siliceous limestone, and (3) comparatively pure limestone. The following analyses show specimens of these three classes:

Analyses of limestones from the Boone chert.

	Allen's quarry, Polk Bayou, 13 N., 6 W., sec. 4.	Near Victor post-office, 13 N., 7 W., sec. 10.	Mill Creek, 16 N., 18 W., sec. 13.
	per cent.	per cent.	per cent.
Lime (CaO)	55.17	55.42	56.14
Magnesia (MgO)	trace	.39	trace
Silica (SiO_2)	1.61	.68	.30
Alumina (Al_2O_3)	.00	.00	.00
Iron oxide (Fe_2O_3)	.14	.32	.06
Potash (K_2O)	.14	.19	.12
Soda (Na_2O)	.09	.19	.08
Phosphoric acid (P_2O_5)	.10	.17	trace
Loss on ignition, CO_2 and organic matter	43.13	43.56	43.77
Total	100.38	100.92	100.47
Water at 100°–115° C	.057	.09	.49
Carbonate of lime ($CaCO_3$)	98.29	98.59	100.23

Partial analyses of limestone from the Boone chert.

	Loster's spring.	Jones quarry.	Pond Mountain, 20 N., 26 W., sec. 23.	Lime-kiln at Rogers.	Brush Creek, Madison co., 17 N., 28 W., sec. 25.	17 N., 26 W., sec. 15.	Denieville, Independence co.
	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.
Lime (CaO)	54.92	53.66	55.06	54.89	55.09	56.15	55.12
Insoluble (silica)	1.47	4.38	....	....	.50	.19	.28
Magnesia (MgO)	....	....	.03	.21	....	....	.45
Loss on ignition (CO_2 etc.)	....	....	....	....	43.61	43.58	
Total	56.39	58.04	55.09	55.10	99.20	99.92	55.85
Water at 110-115 C	.10	.31	....	....	.03	....	
Carbonate of lime ($CaCO_3$)	98.07	95.82	98.32	98.02	98.37	100.25	98.43
Carbonate of magnesia ($MgCO_3$)	....	....	....	....	....	....	.95

Partial analyses of chert and limestone.

	Chert from Polk Bayou, Independence co.		Siliceous limestone from Little Rocky Bayou, Stone co.
	per cent.	per cent.	per cent.
Carbonate of lime ($CaCO_3$)	.....	.....	47.92
Silica (SiO_2)	98.80	99.21	52.80
Loss on ignition	0.33	0.28	.....
Total	99.13	99.49	100.72
Water at 110°–115° C.	0.23	0.10	0.09

These analyses show a stone of remarkable purity, only one specimen containing less than 98 per cent. of carbonate of lime. It will furnish, on burning, a remarkably pure (fat) lime, and it is almost wholly free from any substance which would injure it for a building stone.

The durability of the stone varies with the quality in different localities. But in nearly all places where it occurs in heavy beds comparatively free from chert it is very durable, and so far as can be judged from the outcrops, is one of the best limestones in the state to resist weathering influences. The Survey has made tests to determine the strength and durability of samples from only one locality. The following tests were made upon coarsely crystalline samples from Mill Creek, Searcy county, two miles west of St. Joe, where it occurs in layers from a few inches to three feet thick, the total thickness of the bed being sixty feet. The stone takes a good

polish and can be used as a marble for either ornamental or structural purposes.

Crushing strength of limestone from the Boone chert.

(From Mill Creek, Searcy county.)

No.	Height of test cube—inches.	Area of pressure—sq. inches.	Total stress in pounds.	Stress per square inch in pounds.
1	1.430	2.144	14,500	6,770
2	1.427	2.145	14,450	6,740
3	1.440	2.288	17,340	7,620
4	1.435	2.296	15,170	6,610
Average crushing stress per square inch				6,935

Absorption test of limestone from the Boone chert.

No.	Dry weight,* beginning.	Weight after being in the water.				Percentage absorbed.
		3 hours.	1 day.	3 days.	60 days.	
1	137.730	....	....	138.200	138.380	.47
2	64.800	65.033	65.082	65.050	65.171	.57
3	31.871	32.010	32.020	32.013	32.077	.64
Average absorption of the three samples						.56

Fire test of a sample of limestone from the Boone chert.

A small sample was heated to a temperature of 600 degrees Fahrenheit in a bath of molten lead and then plunged into a bath of cold water. The specimen cracked badly and crumbled at the edges where the stone was thinnest.

Specific gravity of limestones from the Boone chert.

		Specific gravity.	Weight per cubic foot.
1.	Mill Creek, Searcy county	2.6747†	167.17
2.	Oölitic from Jones quarry	2.6392	164.95
3.	Oölitic from Allen's quarry	2.5820	161.38
4.	Bituminous from Loster's spring	2.6789	167.43
	Average	2.6437	165.23
5.	Block, 14.5 feet by 7.5 feet by 11 inches, weight, 16,500 lbs., from Jones quarry		165.52

*The weight in this and similar tables elsewhere is in grammes, but as the unit is immaterial it is not mentioned in the table.

†Average of ten samples.

The fine-grained and oölitic varieties weather with smooth, hard surface, are very resonant and dress readily in all directions. The coarsely crystalline variety weathers with a loose granular surface in rounded boulders and ledges.

Limestone from the Boone chert as a building stone.—Limestone for structural purposes has been quarried from the Boone chert series at the Jones quarry, five miles from Batesville, and on Brush Creek, in Madison county. That from the former place has been shipped by rail from Batesville to Little Rock, Texarkana, Newport, and Baring Cross. It was used in Little Rock for the lintels, jambs, cornices, water table, and other trimmings of the new court house.* It has had a limited use in other buildings in Little Rock.

It has been used at Texarkana as a trimming for the Union depot and the new Federal building. The front of the new Savings Bank in Batesville is built of this stone, and it has also been used in the Evans and Fletcher buildings in the same place, and for monuments at Batesville and Newport.

Mr. Bartlett, who has had charge of the quarry for more than a year, shipped forty-four car-loads of limestone during the twelve months, ending July 1, 1892, which includes two car-loads for monumental purposes. The largest piece shipped from the quarry was 14.5 feet long, 7.5 feet wide, 11 inches thick, and weighed 16,500 pounds. It was used in the new Federal building at Texarkana.

The limestone quarried on Brush Creek, Madison county, was hauled by wagon to Fayetteville, where it was used in the main building of the Arkansas Industrial University. The stone has been quarried elsewhere for local use in building foundations, chimneys, etc.

When better transportation facilities are afforded large quantities of the limestone from the chert formation will no doubt be used for building purposes, as it is admirably adapted for such use, occurring as it does in layers of different thicknesses and being easy to work and of great durability.

*For illustration of this building see An. Rep. of the Geol. Survey of Arkansas for 1890, Vol. II., p. 55.

Lime from the Boone chert formation.—Except that burnt along the Kansas City, Springfield & Memphis Railway, in Sharp and Fulton counties, which is from limestone of Silurian age, nearly all the lime burnt in North Arkansas, whether for local use or for shipping, has been made from the limestone of the Boone chert formation. Lime has been burnt at the Jones quarry, five miles northeast of Batesville, and at the Allen quarry, two miles north of Batesville, some of which was shipped from Batesville by rail, while some was used in Batesville and vicinity; it has been burnt for several years at Denieville, between Batesville and Cushman, from which point it is shipped by rail to Little Rock and other places. Lime has also been burnt at Eureka Springs, in Dairy Spring Hollow, and at John Morehouse's, on Pond Mountain, for use in Eureka Springs. Lime has been shipped from Garfield, Rogers, and other points on the St. Louis & San Francisco Railway. Lime for local use is burnt from this limestone at Harrison and other places.*

Lime made from the limestones of the Boone chert formation is very pure, what the builders call a fat lime, the chemical analyses of which from the different quarries show the percentage of impurities in it to be very slight.

The use of this stone for marble is described in a subsequent chapter.

Distribution of the limestones of the Boone chert.—The geology of the limestone and marble region of North Arkansas is mapped on the six sheets which accompany this report and which show the details of the distribution of the various geological formations. Each of these sheets will be spoken of here in regard to such points of interest regarding the limestones as cannot be given in the map sheets. The Boone chert area is shown on the accompanying map sheets, and more or less limestone occurs with the chert over the entire area, as has already been stated. No attempt is made to describe or even mention all the localities at which these limestones occur, but only such exposures as promise

*For details of the lime industry, see Chapter XI.

some economic value will be described in this place. While the limestone is exposed in many places, it is oftener concealed by forests, by soil, or by the debris of the accompanying chert.

It will aid greatly in the comprehension of the geology of the region and in the location of the limestone to bear in mind that these beds are more or less persistent, that they are usually horizontal or nearly so, and that an outcrop on one side of a hill or valley is generally repeated on the opposite side, though it may be concealed as suggested.

On the Batesville sheet.—So far as observed the oōlitic variety of limestone of the Batesville region is limited to the east side of Polk Bayou, where there are three separate exposures of it, all no doubt forming part of one continuous bed which is concealed at other places. The most eastern outcrop is in 14 N., 5 W., sec. 19, on Mr. Pierce's farm, where several acres are exposed in thin layers, the surface being strewn with loose slabs. The only use so far made of it has been for lime, which is burnt in a temporary kiln. It is probable, from what has been observed of this stone here and elsewhere, that the shaly structure does not extend far below the surface.

A limestone similar to the one just described occurs in 14 N., 6 W., sec. 25, the northwest quarter. It differs from the other in that it occurs on the surface in layers from two to four feet thick and quite regular, the bedding planes being comparatively even. Many of the joint-planes have irregular openings at the surface, due to infiltrating waters. A quarry known as the Jones quarry has been opened near the base of the hill, from which stone for both building and lime has been quarried. The stone outcrops a vertical distance of sixty feet from the base of the hill at the bottom of the quarry to the hilltop, and can be taken out in pieces as large as can be handled.

Two miles north of Batesville on the east side of Polk Bayou is another outcrop of limestone of the same bed as that at the Jones quarry, but which differs from it slightly in

texture. It has been quarried for lime burning, building and monumental stone. Along the bayou in 13 N., 6 W., sec. 4, an area of several acres is uncovered, or has but a slight covering of chert, yet only one quarry has been opened—that known as the Allen quarry.

At Denieville, on the railroad between Batesville and Cushman, in 14 N., 7 W., sec. 35, is an outcrop of chert limestone half a mile or more in length along the hill on the east side of Spring Creek. The stone differs greatly in texture from that east of Polk Bayou, being coarsely crystalline, fossiliferous, slightly bituminous, not so regularly bedded, and containing some intercalary chert. The total thickness of the exposure is about sixty feet. No building stone has been quarried at Denieville, but larger quantities have been quarried for lime than at any other point in Independence county. (See Chapter XI.)

The largest areal exposure of the limestone of the chert formation in Independence county is west and northwest from Batesville, in 13 N., 7 W., and 14 N., 7 W., including the region known as "The Barrens," one of the richest farming regions in the county. The stone differs from that at any of the places described above; it is fossiliferous, but not so much so as that at Denieville, and while fully as crystalline the crystals are smaller than at the latter place; it is strongly bituminous, dark colored in places, bleaching on exposure, firm, close-grained, compact, and resonant.

On the road from Batesville to Mountain View the limestone of the Boone chert first appears near the middle of section 10 (13 N., 7 W.), whence it was traced by occasional more or less extensive outcrops through the northeast quarter of section 10, the south part of section 3, and in a northwest direction diagonally through section 4; two or three boulders show in section 31 (14 N., 7 W.), and an extensive exposure in section 30, around the south and west base of Childress' Mountain; whence it outcrops down the ravine from the spring at the northwest end of the mountain through sections 25 and 35 (14 N., 8 W.), to Webb Chapel in section

35 on the Mountain View-Batesville road. The western limit of the area has been traced through the eastern part of section 5 (13 N., 7 W.), the northeast quarter of section 8, and through section 9, close to the middle, to the point of starting in section 10. In this area of three or four square miles the limestone outcrops in many places and in all places is not far below the surface, the finest exposures being in section 10 (13 N., 7 W.), at Mr. Barnes'; on the northeast quarter of section 9 (13 N., 7 W.), on the hill north and east of Mr. Headstream's; and in the southeast quarter of section 4, same township, southeast of Victor post-office. The total thickness of the rock could not be ascertained as there are no deep erosions in it. At Mr. Wright's, 13 N., 7 W., section 9, the northwest quarter, is a well said to be forty-five feet deep which is apparently all in this rock. There is a drilled well at Mr. Headstream's, 13 N., 7 W., section 9, the middle of the north part, which Mr. Headstream states is 135 feet deep, drilled all the way in this rock without reaching the bottom of it.

The area just described is separated by a high ridge from a somewhat similar exposure which occurs about the big spring (Loster's spring) on the old Spanish grant, in what would be section 21 (13 N., 7 W.), and up the ravine from the spring in a northwest direction through section 16, and the northeast quarter of section 17, same township. It occurs in the bottom of the ravine, along the hillsides, and in the side ravines. In some places it contains intercalary chert and weathers into thin dark colored slabs, which are highly crystalline, very resonant, and fossiliferous in places. No use has been made of the limestone in either of the two areas last described beyond a small quantity used in making lime for local demand.

On the Mountain View sheet.—So far as known to the Survey no limestone of the chert series has been quarried in Stone county, except a limited supply for local use in making lime. The limestone of the Boone chert formation found on the Mountain View sheet varies slightly in texture, but it more

closely resembles that quarried at Denieville than any of the other varieties described. It forms an irregular and broken outcrop near the southern border of the Boone chert area shown on the Mountain View sheet. On Cagen and Dry Creeks it is thirty feet or more in thickness, the contact with the chert above and below not being clearly defined. On Little Rocky Bayou it is forty feet thick and very fossiliferous. On Hell Creek, northeast of Mountain View, and on Dry Creek, northwest of Mountain View, it outcrops in large quantities in a bed fifty feet thick. On Roasting-ear Creek it is from forty to sixty feet in thickness, with 100 feet of chert between it and the St. Clair marble below.

On the Harrison sheet.—The largest and most valuable outcrops of the limestone of the Boone chert formation in the area covered by the Harrison sheet are on Mill Creek, Searcy county, and Mill Creek, Newton county. That on Mill Creek, Searcy county, is two miles west of St. Joe, in 16 N., 18 W., section 13 (see p. — for description). On Mill Creek, Newton county, it outcrops in the vicinity of Marble City in the southern and southwestern parts of 17 N., 20 W. The stone in this region is not so highly crystalline as in Searcy county, but occurs in larger quantities, the bed in some places being over two hundred feet thick. No use has been made of the stone in either place. Good marble, building stone, or stone suitable for lime burning could be obtained at either place. Large quantities of limestone outcrop around Rally Hill and Valley Springs, in 17 N., 19 W., but it contains so much intercalary chert as to be of little value except for lime. On the west side of the wagon road south of Valley Springs, in 17 N., 19 W., section 14, is an outcrop where fine building stone could be obtained.

On the Carrollton sheet.—In the southeast part of 17 N., 21 W., in the ravines leading into "The Basin," are large outcrops of chert limestone from which good building stone could be obtained. It also outcrops on Henson Creek, in 16 N., 21 and 22 W. In many other places in the area covered by the Carrollton sheet, good stone for lime burning

occurs as well as small outcrops of good building stone; but no notes of special importance have been made by the Survey on the details of these outcrops on the Carrollton sheet.

On the Eureka Springs sheet.—On the north end of Pond Mountain limestone of the Boone chert formation has been quarried for lime. It has a partially oölitic structure and occurs in a bed twenty feet or more in thickness, seventy feet below the top of the chert bed, and contains some intercalary chert. On Kennedy Branch of War Eagle Creek, in 17 N., 26 W., section 15, three miles north of Huntsville, is an outcrop of oölitic limestone which has been quarried for lime and where excellent building stone could be obtained. But a small quantity is exposed at the quarry and the thickness of the bed is concealed by the talus of the chert, but the quality of the stone is sufficient to justify further work at the quarry. On Brush Creek, in 17 N., 28 W., section 25, limestone from the chert has been quarried for use in building the Arkansas Industrial University at Fayetteville. The stone which has an oölitic structure occurs on the north bank of Brush Creek in a ledge three to four feet thick. The stone is a good one for building purposes, and should railway transportation be afforded, it might be quarried extensively and profitably. Large quantities of limestone are exposed in the vicinity of Goshen in the southern part of 17 N., 28 W., where good building and lime rock could be obtained.

In the region west of that shown on the Eureka Springs sheet, in Benton and Washington counties, large quantities of limestone of the Boone chert formation are exposed. At Garfield, Rogers, and other points along the St. Louis & San Francisco Railway it has been burned for lime.*

*See the Survey's reports on Washington and Benton counties.

CHAPTER VIII.

The Silurian Limestones of North Arkansas.

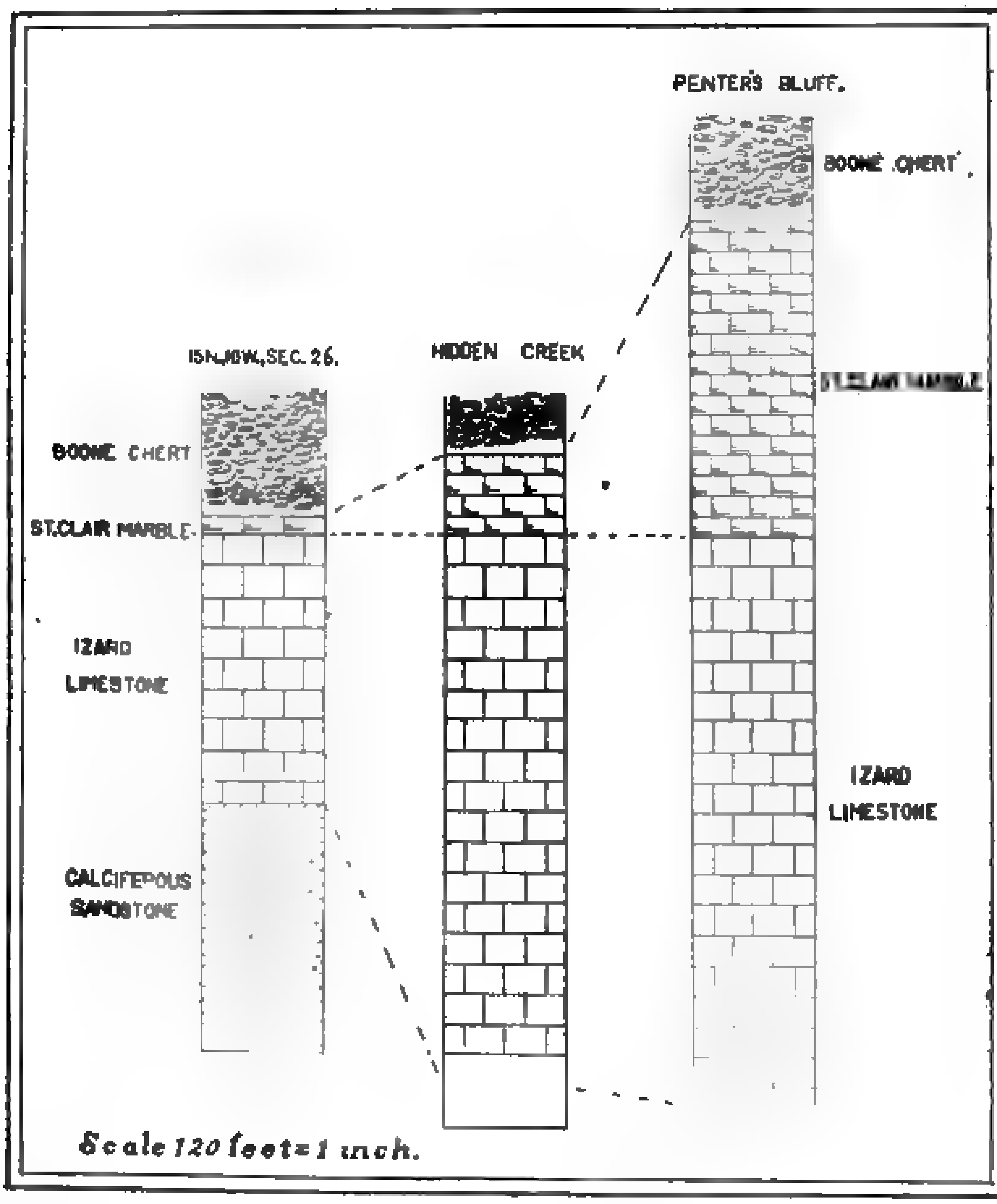
THE IZARD LIMESTONE.

The Izard limestone was named from Izard county by the State Geologist, because it occurs in large quantities in the southern part of that county.

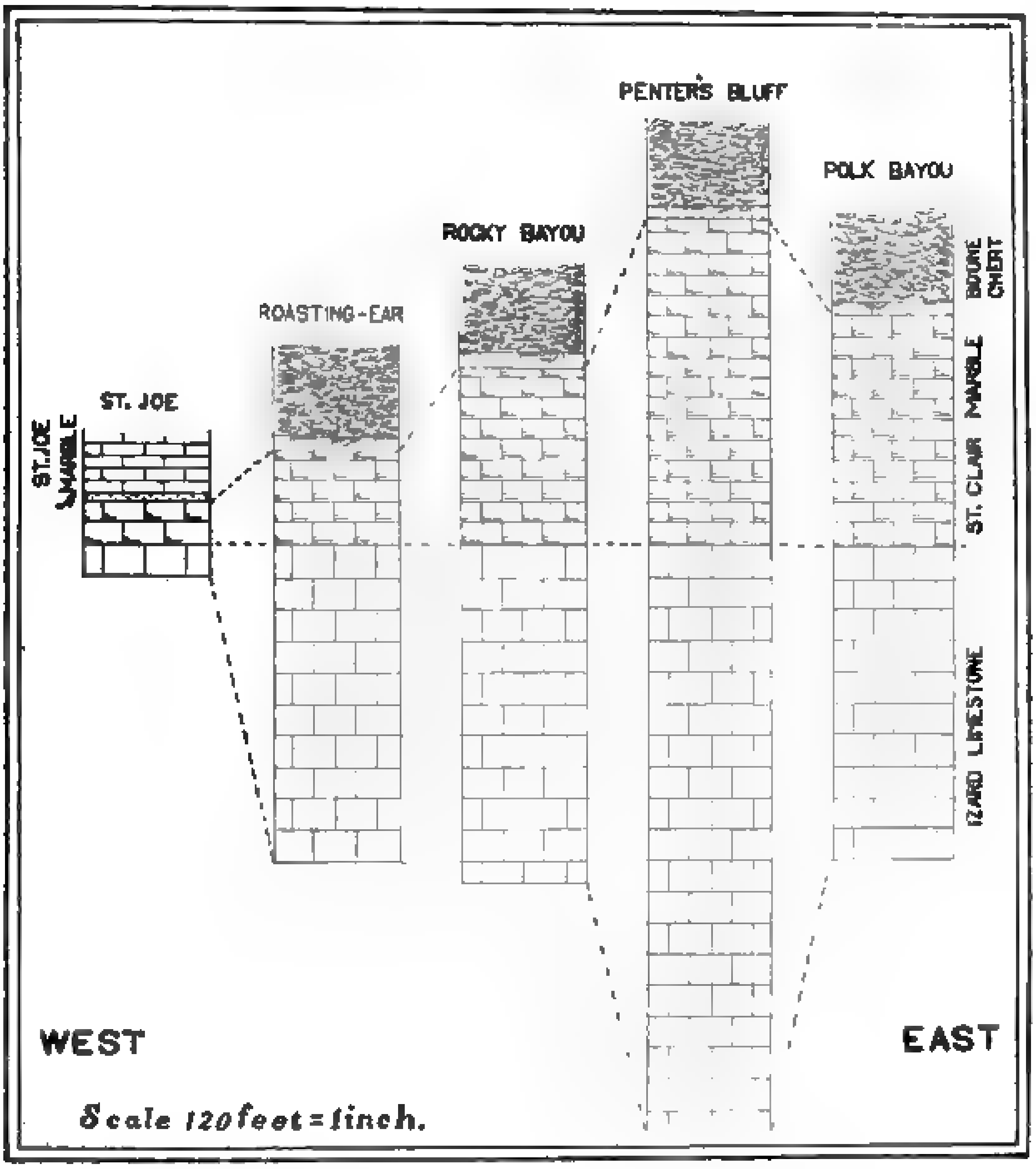
Geologic position.—The Izard limestone is almost entirely without fossils, so that its geologic age could be determined only by referring it to the formation immediately above it; this overlying formation is the St. Clair marble which Dr. H. S. Williams places in the Silurian between the Niagara and Trenton. It is underlain by a saccharoidal sandstone which is considered by the same authority to be Calciferous. At the base of the Izard limestone there are local developments of a dark colored siliceous limestone which in some places is twenty feet or more in thickness.

Thickness.—The maximum thickness of the Izard limestone occurs on White River at Penter's Bluff, Izard county, where 285 feet are exposed, while the bottom of the bed extends below the level of the river, so that the total thickness cannot be ascertained. From this point it gets gradually thinner eastward to range 4 W., on the Paleozoic border in Independence county, and westward to range 18 W., near the western border of Searcy county. It thus has an east-west extent of more than eighty miles. The limits of its exposure north and south vary from three to ten miles, depending upon the topography. The greatest thickness occurs along the southern limit of the outcrop, but the thinning to the north is due partly to degradation and partly to the original thinning of the bed.

A better idea of the change in thickness may be obtained by reference to plate III., which shows a series of sections



VERTICAL SECTIONS OF BLUFFS ON WHITE RIVER SHOWING THE THINNING OUT OF THE ST. CLAIR MARBLE AND THE IZARD LIMESTONE.



SECTIONS ACROSS THE ST. CLAIR MARBLE AND THE IZARD LIMESTONE.

in a general east-west direction. The section on Polk Bayou is not at the eastern limit of the limestone, but is the most eastern point at which it was measured. It is much thinner on Bayou Dota further east, but is there so covered with debris that no satisfactory measurement could be obtained. At Rocky Bayou it is 160 feet thick. The disproportion between the last two sections on the plate, the one on Roasting-ear Creek (150 feet), and the one at St. Joe (15 feet), is partly due to the much greater distance between them, and partly to the fact that St. Joe is further north, as, on Jimison's Creek, southwest from St. Joe, the limestone is fifty feet thick. Plate IV. shows the change in thickness along White River; at Penter's Bluff, the lowest exposure on the river, the limestone has a thickness of 285 feet, while in 15 N., 10 W., section 26, opposite the lower end of Round Bottom, the highest point at which it was measured, it is 130 feet thick. It extends much further up the river and ends somewhere between the mouth of Livingstone Creek and Rappied Branch. The middle section is on the east end of the river bluff above the mouth of Hidden Creek, where the Izard limestone is 250 feet thick.

Description of the Izard limestone.—The Izard limestone is a smooth, fine-grained, compact, homogeneous, non-fossiliferous, evenly bedded limestone, breaking with a conchoidal fracture, and is mostly of a dark blue color, varying locally to buff, light and dark gray, and almost black. As shown in the one sample tested, it is a comparatively heavy limestone, more so than any of the marbles of the state, having a specific gravity of 2.7272 corresponding to a weight of 170.45 pounds per cubic foot. A partial chemical analysis was made of two different samples with the following results:

Partial analyses of Izard limestone.

	From Polk Bayou.	Lithographic quarry, Lafferty Creek.
	Per cent.	Per cent.
Insoluble in hydrochloric acid..........	1.44	.34
Carbonate of lime ($CaCO_3$)............	97.97	98.67
Carbonate of magnesia ($MgCO_3$).......	....	2.14
Total..........................	99.41	101.15

While the percentage of lime is not so high as it is in some of the marbles and limestones of the Boone chert, yet it is a comparatively pure lime carbonate. No other samples were analyzed, but several specimens digested in hydrochloric acid were found to be almost wholly soluble, showing it to be a nearly pure limestone.

In some places small crystals of iron pyrites are scattered through the rock, some of which have oxidized into limonite or turgite. In no place were these crystals observed in sufficient quantities to materially injure the strength of the stone, yet they are abundant enough in many places to discolor it. In a few places copper pyrites occurs.

The bed is intersected by numerous joint-planes at nearly right angles with each other and with the bedding planes, which fact greatly facilitates the quarrying of it. On many of the hillsides large numbers of rectangular blocks of various sizes are scattered over the surface. The occurrence of these blocks is due to the action of dissolving and disintegrating agencies, where the percolating water and ice acting along the stratification and joint-planes, separate the blocks from the mass with comparatively smooth faces. A good evidence of the durability of the Izard limestone is shown in the square corners, sharp edges, and firm, solid surfaces shown in these weathered blocks. Of course there are local variations in the quality of the stone, and occasionally a place is found where weathering has left it in a shelly, crumbling condition, but so far as observed the greater part of this limestone is free from such imperfections.

As a building stone.—Its smooth bedding planes, its numerous smooth, rectangular joint-planes, its compact, fine-grained, homogeneous texture, and consequent strength and durability make the Izard limestone a valuable building stone for rough or heavy masonry, such as foundations, bridge piers, retaining walls, or any kind of superstructure where a rock face is not objectionable. Its decidedly "plucky" nature precludes it from all carved or fine-tooled work.

It will be found valuable in the future for building piers and

abutments in bridging the numerous streams of North Arkansas which are now almost entirely bridgeless. In railway construction it will also be of value for ballast and the construction of culverts. Its brittleness and the ease with which it can be obtained add to its importance for railway ballast, and the same properties likewise make it useful for macadamizing common roads if it is covered with harder material, as limestone is poor surface material for a macadamized road.

For lime.—The purity of the Izard limestone, the great quantity of it, the facility with which it can be prepared for the kiln, and the ease with which it can be burnt, make this the most valuable rock in the state for lime burning, and it is doubtful whether there is a rock found anywhere superior to it for making common lime. Some of the overlying marbles make a purer lime, but their crystalline texture makes them more difficult to prepare for the kiln and requires more heat to reduce them. The ease with which it can be prepared for the kiln is due to the numerous joint-planes, by means of which it can be easily quarried, and to its brittleness which renders it easy to break in pieces of the proper size for the lime-kiln. A kiln placed on the face of one of the numerous limestone bluffs or steep hillsides could be supplied for many weeks with no other tools than a sledge hammer and wheel barrow. A little dynamite judiciously applied in the face of one of the perpendicular or overhanging bluffs would bring down immense quantities of rock which would require but little further work to prepare it for the kiln. Should there be the necessary transportation facilities and proper demand, the only drawback to an extensive development of the lime industry in the Izard limestone region would be the lack of coal for fuel; but in the absence of this there is an excellent substitute in the enormous supply of wood.

For lithographic stone.—The greater part of the Izard limestone is very fine-grained, but certain layers are so much so as to suggest a good quality of lithographic stone. A somewhat extended search has been made by the citizens of certain sections for a lithographic stone, but thus far the search

has been unsuccessful. The nearest approach to success was at Dr. Warden's, on West Lafferty Creek, where considerable work was done a few years ago, and it is reported that some good samples were obtained which answered all the required tests, but the work suddenly ceased, as it was found that the greater part of the stone was worthless for lithographic purposes on account of the fine crystalline particles scattered through it. The crystalline parts are in some places but single crystals; in others they are fine, hair-like veins, so small as to be almost invisible to the naked eye. These crystals splinter or break with ragged edges under the engraver's tool, thus injuring the stone for fine work. The layers from which the lithographic stone was obtained are from two to four inches thick with a total thickness of about two feet; they are overlain by twenty feet of Izard limestone and underlain by over 170 feet of the same rock. In color it is drab and light to dark gray; the buff colored variety, common in many neighboring localities, does not occur at this quarry.

Distribution of the Izard limestone.—The Izard limestone occurs in five counties, viz.: Independence, Izard, Stone, Searcy, and Newton, and covers part of the area on the Batesville, Mountain View, and Harrison sheets of the accompanying maps, and a very small area on the Carrollton sheet. The areal distribution is shown only on the Batesville sheet. Its position on the other sheets may be approximately ascertained, however, by observing that it lies immediately underneath the St. Clair marble, and that it generally covers a wider strip and extends further north, thus covering a somewhat larger area than the marble. The increased area is due to the greater thickness and more favorable stratigraphic position of the limestone. On the Mountain View sheet it does not occur north of the Leatherwood Mountains. On the Harrison sheet it is confined mostly to the south side of Buffalo River, limited exposures occurring on Water, Tomahawk, Mill, and Jimison's Creeks, on the north side of the river.

As there is but very little variation in its appearance over

the entire area, only a few of the more prominent exposures will be described.

The lowest exposure of the Izard limestone on Polk Bayou is at the mouth of Cave Creek, above which point large quantities are exposed on the hills. On Cave Creek the outcrop is comparatively small, but on Sullivan's Creek and Prairie Creek, and in the short ravine in 14 N., 6 W., section 19, it occurs in a bed varying from 100 to 150 feet in thickness, in layers varying from one inch to three feet thick. In a few places the bottom layers adjoining the underlying sandstones are siliceous.

It is found in quantity on all the main branches of Lafferty Creek and of all thicknesses up to 200 feet. In a few places it occurs in almost perpendicular bluffs, but more commonly in steep terraced slopes. The finest exposures are those along the tributary flowing west from Cushman, known as Blowing Cave Creek; that in the ravine in 14 N., 8 W., section 13, the north part of the section; and that on the lower part of West Lafferty Creek for four miles above its junction with East Lafferty. In sections 3 and 10 (14 N., 8 W.) are areas especially noteworthy both for the quantity and quality of the Izard limestone there exposed.

At Penter's Bluff on White River and in the adjoining region this limestone is in admirable position for quarrying. Penter's Bluff itself is an irregular, almost perpendicular wall more than 400 feet high, 285 feet of the base being Izard limestone. At and in the rear of the lower end of the bluff is a ravine from a quarter to half a mile in length, penetrating the hill in a direction but slightly divergent from the course of the river, thus leaving a high narrow wall with an abrupt face riverward and standing so close to the river bank as scarcely to leave room for the road along its base. The rear of this wall is a steep terraced slope into the ravine mentioned. The south end of the wall is tolerably abrupt for sixty to seventy feet, above which point the slope is more accessible so that one can, with a little difficult climbing at the start, ascend to the highest point of the bluff by traversing it lengthwise. The rocks have a perceptible dip of from 2° to 8° to the south and east. About

a quarter of a mile of the south end of the bluff consists entirely of the Izard limestone.

The cost of quarrying and preparing this limestone for burning would be comparatively small, and as the supply is practically inexhaustible, with abundance of wood in the immediate vicinity and White River navigable a large part of the year, the facilities for burning lime at this point are excellent. Good building stone could be quarried at little expense, and the refuse used for lime burning.

West of Penter's Bluff on the north side of White River the limestone is covered in only a few places by the chert debris, but outcrops almost continuously along the hills next to the river and on the lower course of all its tributaries as far at least as Mount Olive.

The largest and most conspicuous outcrop of Izard limestone west of Penter's Bluff is on Wilson Creek in the northwestern part of the Batesville sheet. The base of the hill on each side of the creek is composed of the Izard limestone, the thickness of the exposure being 100 to 200 feet; the bottom of the bed is not exposed. In some places the limestone outcrops in solid continuous layers, while in others the surface is covered with more or less regular rectangular blocks, the result of weathering influences. The position of the stone here for quarrying is all that could be desired.

In Stone county the Izard limestone is extensively developed along the south side of White River in the eastern part of the county. The hills along the river from a point opposite Penter's Bluff to the lower end of Round Bottom mainly rest upon this limestone, which forms from 100 to 200 feet of the base. Up the river from Round Bottom, the base of the hills is composed of the saccharoidal sandstone, the Izard limestone lying near the top of the hill. Going northward it gradually approaches the tops of the hills, until it thins out and disappears entirely in the northern part of the county, being replaced by the underlying rocks. It is exposed in large quantities along Cagen and Dry Creeks, Rocky Bayou, Hell Creek,

and South Sylamore Creek, and in smaller quantities on North Sylamore and Livingstone Creeks.

In Searcy county the Izard limestone is not nearly so thick as it is further east, but it gradually thins to the west. It occurs in considerable quantities along Big, Spring, Bald Knob, Little Rock, Rock, Brush, and Bear Creeks on the south side of Buffalo River; and on Mill and Jimison's Creeks on the north side.

In the eastern part of Newton county a small quantity of Izard limestone occurs along Buffalo River, the most western outcrop noted being in 16 N., 21 W., section 26, about one mile below Jasper.

THE MAGNESIAN LIMESTONES.

No detailed study of the magnesian limestones has been made by the Survey; the following are the general observations made on them while mapping the marble region:

Position and character.—The Silurian rocks below the Izard limestone consist of a series of sandstones, magnesian and siliceous limestones, and cherts. One or more beds of magnesian limestone occur at all places where there is any large vertical exposure of the Silurian rocks, but no attempt has been made to correlate them or to trace their distribution. So far as ascertained, all the magnesian limestones of the region belong to the Calciferous group. To quote the words of Dr. H. S. Williams: "The lowest rocks examined are a series of several hundred feet thickness composed of irregular alternations of magnesian limestone and sandstones, the prevailing rock being a somewhat brownish-gray arenaceous magnesian limestone, a typical calciferous 'sandstone,' a good exposure of which is seen at The Narrows west of Eureka Springs on the White River. This has few fossils, but the few seen indicate the age of the Calciferous of New York."*

It is probable that these limestones are continuous with some of the beds described as the First, Second, and Third Magnesian limestones in the Geological Reports of Missouri, but no correlations have been attempted.

*Letter to the State Geologist, December 1, 1890.

In a recent publication of the Geological Survey of Missouri that arrives as this goes to press, these rocks, which had there been considered as Lower Silurian, are now classed as Cambrian. The State Geologist of that state says: "The recent investigations of the Geological Survey are leading to the conclusion that the magnesian limestone and associated sandstone strata immediately about the Archaean hills of the Southeast are all of Cambrian age, rather than that part are Lower Silurian as has heretofore been held. Moreover, it is probable that the same applies to the rocks of the whole central portion of the Ozark uplift. * * * The evidence in support of this will be adduced in a forthcoming later publication."*

The principal varieties of the magnesian limestones of North Arkansas are light gray, almost white, cream colored, and a dark gray, becoming almost black in places. The last variety is highly siliceous, and is charged with carbonaceous matter which gives the dark color. The gray and cream colored varieties are important from an economic standpoint, as excellent building stone of both colors is obtained at various places over the area.

The soft light gray and buff colored varieties, the so-called "cotton rock," have a slightly conchoidal fracture, a fine grain, and work easily in all directions. One sample of the buff colored rock has a specific gravity of 2.6359, equivalent to a weight of 164.74 lbs. per cubic foot—a comparatively light stone. Samples of the light gray colored stone have a specific gravity of 2.659 and 2.747, the first from Leatherwood Switch, the second from Waldon Switch, on the Eureka Springs Railway.

The magnesian limestone occurs in regular stratified layers varying from two inches to ten feet in thickness. While in a few places a shaly structure is developed on the weathered exposures, in general the weathered surface develops no seams other than the regular bedding planes, which are comparatively even, but in some places are partly concealed, so that two separate layers in one place not infrequently merge into one in another place. These concealed stratification planes are made

*Geological Survey of Missouri, Vol. II., Report on Iron Ores, p. 17.

use of by the quarryman in quarrying flagstone or curbstone, as they enable him to split the stone very easily. In many places along White River and its tributaries the magnesian limestone forms regular terraced slopes.

Composition of the magnesian limestones.—In composition the stone varies in the proportion of magnesia and silica, as shown by the following analyses:

Partial analyses of Arkansas magnesian limestones.

Number.	Locality.	Iron and alumina.	Silica and silicates.	Lime (CaO).	Magnesia (MgO).	As carbonates.	
						Lime ($CaCO_3$).	Magnesia ($MgCO_3$.)
1	Leatherwood Switch (south side)	4.72	8.65	26.83	18.68	47.91	39.23
2	Leatherwood Switch (north side)	*	*	27.74	19.05	49.53	40.00
3	Waldon's Switch	*	*	27.70	19.45	49.47	40.85
4	White River (18 N., 13 W., sec. 36)	0.89	13.52	27.01	18.27	48.23	38.36
5	Near Mt. Hersey	1.21	8.01	31.69	16.52	56.58	34.69
6	20 N., 18 W., sec. 35	*	*	....	17.50	....	36.75
7	19 N., 17 W., sec. 17	*	*	26.82	17.72	49.89	37.21
8	19 N., 17 W., sec. 7	*	*	18.10	11.44	32.25	24.02
9	19 N., 18 W., sec. 11	*	12.76	27.03	18.04	48.22	37.89
10	Depot, Eureka Springs	*	14.71	26.57	17.03	47.43	35.76
11	Three miles S. E. of Yellville	*	12.07	27.18	18.05	48.53	37.91

Complete analyses of Arkansas magnesian limestones.†

Constituents.	Hoppe mine, Lawrence co.	Koch mine, Lawrence co.	Wood's mine, Marion co.
Carbonate of lime ($CaCO_3$)	53.998	50.075	50.041
Carbonate of magnesia ($MgCO_3$)	35.059	32.487	42.317
Insoluble silicates	6.701	10.935	3.191
Potash (K_2O)	.106	.136	.435
Carbonate of iron ($FeCO_3$)	2.253	....	....
Carbonate of zinc ($ZnCO_3$)	1.978	....	1.950
Iron, alumina, and manganese	....	1.482	3.023
Organic matter and loss	....	4.985	....

*Present but not determined.

†From First Rep. of a Geol. Rec. of the Northern Counties of Arkansas, by D. D. Owen, pp. 174–5.

The analyses show that the lime and magnesia in most of the samples are in almost the exact relation in which they occur in true dolomite. This is better shown in the accompanying table, in which the first column shows the lime and the second the magnesia in the samples analyzed, while the third column shows the percentage of magnesia required for true dolomite.*

Carbonate of magnesia in Arkansas dolomites and the amount required for theoretical dolomite.

Number.	Locality.	Carbonate of lime ($CaCO_3$).	Carbonate of magnesia ($MgCO_3$).	Carbonate of magnesia necessary for a true dolomite.
1	S. side Leatherwood Switch	47.91	39.23	40.24
2	N. side Leatherwood Switch	49.53	40.00	41.60
3	Waldon's Switch	49.47	40.85	41.55
4	White River, 18 N., 13 W., sec. 36	48.23	38.36	40.51
5	Near Mt. Hersey	56.58	34.69	47.52
7	19 N., 17 W., sec. 17	49.89	37.21	41.90
8	19 N., 17 W., sec. 7	32.25	24.02	27.08
9	19 N. 18 W., sec. 11	48.22	37.89	40.50
10	Depot, Eureka Springs	47.43	35.76	39.84
11	Three miles S. E. of Yellville	48.53	37.91	40.76
12	Hoppe mine, Lawrence co	54.00	35.06	45.35
13	Koch mine, Lawrence co	50.08	32.49	42.06
14	Wood's mine, Marion co	50.04	42.32	42.03

It will be seen that in only three of the samples does the amount found differ from the theoretical requirement more than 5 per cent.; in six of them the difference is less than 3 per cent., and in Nos. 3 and 14, it is less than 1 per cent. The variation may be even less than is indicated by the table, as a small amount of the magnesia or lime might be replaced by iron and still retain its true mineral nature (see p. 16). Hence all the samples analyzed may properly be called siliceous dolomites, except, perhaps, No. 5, which contains 15.28 per cent.

*This was obtained by computation, using the following proportion: 54.35, the percentage of carbonate of lime in pure dolomite, is to 45.65, the percentage of carbonate of magnesia in true dolomite, as the per cent. of carbonate of lime in the sample, is to x, the required per cent. of magnesia.

of carbonate of lime in excess of that required to form true dolomite. In sample No. 4, the only one examined under the microscope, the silica is in an amorphous state interspersed among the microscopic dolomite crystals.

Other varieties which were not analyzed are more highly siliceous; in some of them the silica occurs in the form of sand grains. In some localities, noticeably at The Narrows on the Eureka Springs Railway, the silica has crystallized in small geodic cavities. Not infrequently the soft, easily cut dolomite ("cotton rock," as it is popularly called) is interstratified with hard siliceous layers, which contain concentrically-banded, nodular, agatized chert.

Economic uses.—Their soft and pleasing colors, their homogeneous and finely crystalline texture, the durability and ease with which they can be worked, render the magnesian limestones beautiful and valuable building stones. They dress easily in all directions, and when first quarried are so soft as to be cut with great ease, but harden somewhat upon exposure. The finest varieties are especially adapted to carved or fine-tooled work. As magnesian lime is not in favor with American builders, it will probably have little use for lime making. Some of the more impure varieties, however, would furnish hydraulic lime.

Large quantities of the magnesian limestone have been quarried along the Eureka Springs Railway and shipped to various points. It has been quarried in small quantities at the depot at Eureka Springs; in the mouth of Williams Hollow, nearly two miles north of the town; and in much larger quantities at Skelton Switch, 21 N., 26 W., section 28; north of Leatherwood Switch in 21 N., 26 W., sections 21 and 16; between Leatherwood Switch and White River on the west side; at the mouth of Butler Creek, west of Beaver; at Waldon Switch, 21 N., 27 W., section 24; and in smaller quantities at intermediate points.

The quarries are nearly all on or near the same geological level. While good stone occurs above and possibly below that

quarried, the beds of desirable stone are separated by layers of more siliceous rock.

Considerable quantities of the magnesian limestone or dolomite have been used for building purposes in Eureka Springs. It was used to build the Crescent Hotel, one of the finest buildings in the state, the stone for which was mostly quarried at Skelton Switch, a quarry which is now abandoned. The Presbyterian Church on Spring Street, Major Penn's dwelling on the mountain, the Califf building on S. Spring Street, W. J. Sandford's dwelling on Spring Street, and the hardware store near the post-office are all built of dolomite obtained along the Eureka Springs Railway. Besides its use in the above mentioned buildings, the stone has been used extensively at Eureka Springs for sidewalks, foundations, retaining walls, etc. The piers of the railway bridge over White River on the Eureka Springs Railway are built of dolomite quarried along the railway. Stone was also shipped from these quarries to Van Buren, Arkansas, to construct the piers and abutments of the railway bridge over the Arkansas River.

Besides that used in Eureka Springs and in the railway bridges mentioned above, considerable quantities of dolomite have been shipped to various points from quarries along the Eureka Springs Railway between Eureka Springs and the Missouri State line. But most of it has been shipped from the Leatherwood and Waldon Switches, and has gone to St. Louis, Kansas City, Springfield, Joplin, Republic, Monette, and Aurora, Missouri; and to Bentonville, Fort Smith, and Van Buren, Arkansas, where it has been used for building, flagging, curbing, sewer-caps, etc. The quarries have been in operation since 1882.* From March 1 to September 1, 1891, the Tyler, Wilcox Stone and Marble Company shipped forty car-loads to St. Louis. In the same interval G. W. Carson & Co. shipped fifty-five car-loads to different points. Mr. Beaver, at Beaver, was the only other party engaged in shipping the stone at that time, and the statistics of his shipments have not been received. T. G. Trestrail & Co., Beaver, Arkansas, bought the interest of

*It is to be regretted that all the figures relating to shipments are not availab e.

the Tyler, Wilcox Stone and Marble Company, and during the month ending November 14, 1892, shipped sixty car-loads. In the same month G. W. Carson & Co. shipped 29 car-loads.

A small quantity of the Silurian dolomite has been used for building at Yellville, Marion county, and it has had a local use for building chimneys, foundations, spring houses, fences, etc., throughout the region where it occurs. It is especially adapted for local use, as it occurs in thin strata, and is easily cut, broken, and dressed.

A great deal of magnesian limestone has been quarried along the Kansas City, Springfield & Memphis Railway, in Fulton and Sharp counties, and it has been extensively used by that railway for bridge piers, culverts, etc. The quarries have not been visited, except at Black Rock, and no statistics of the amount quarried in those counties have been obtained.

Hydraulic limestones are liable to occur among the more impure varieties of the magnesian limestones, and are reported to exist in some localities, but no reliable information has been obtained of any which had been so used and it has not been possible for the Survey to undertake a systematic investigation of this subject. The table on page 123 shows that the manufacture of hydraulic lime is an important industry in some states of the Union, and it is to be hoped that the subject will yet receive the attention to which it is entitled in Arkansas, for it seems probable that hydraulic limestones will be found in the area north of the Boston Mountains. Some of the specimens of the magnesian limestone analyzed by the Survey are very similar in composition to the Water-lime of New York State, and other hydraulic limestones, as may be seen from the accompanying table.

Analyses of hydraulic limestones compared with the dolomites of Arkansas.

Number.	Locality.	Carbonate of Lime.	Carbonate of Magnesia.	Silica.	Alumina.	Iron oxide.	Potash and soda.	Water and organic matter.
		P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.
1	Chittenango, N. Y.	44.64	37.44	11.76	2.73	1.50	....	1.50
2	Ulster county, N. Y.	45.54	25.94	15.37	9.13	2.25	....	1.20
3	Louisville, Ky	50.43	18.67	25.78	2.98	....	.45	
4	Milwaukee, Wis	45.54	32.46	17.56	1.41	3.03	....	
5	Milwaukee, Wis	48.29	29.19	17.56	1.40	2.24	....	
6	Milwaukee, Wis	41.34	34.88	16.99	5.00	1.79	....	
7	Water-lime, N. Y.	48.40	34.30	13.85	....	1.75	....	1.70
8	Leatherwood, Ark.	47.91	39.23	8.65	4.72	....	....	
9	18 N., 13 W., sec. 36, Ark	48.23	38.36	13.52	0.89	....	....	
10	Eureka Springs, Ark	47.43	35.76	14.71	....	....	....	
12	Near Yellville, Ark.	48.53	37.91	12.07	....	....	....	
13	19 N., 18 W., sec. 11, Ark	48.22	37.89	12.76	....	....	....	

NOTES. Nos. 1 and 2 are limestones which have been used extensively for hydraulic lime n New York. Mineralogy of New York, by Lewis C. Beck, Albany, 1842, pp. 80 and 78.

No. 3, 2d report of the Geological Survey of Kentucky made during the years 1856 and 1857 by D. D. Owen, Frankfort, 1857, p. 220.

Nos. 4, 5 and 6—Transactions of the American Institute of Mining-Engineers. Vol. VIII., p. 507, Dr. R. D. Irving says: "A very elaborate series of tests by D. J. Whittemore, chief engineer of the Milwaukee and St. Paul Railroad, shows that the cement made from it exceeds all native and foreign cements in strength except the famous English Portland cement."

No. 7.—James D. Dana, Manual of Geology, p. 237.

Nos. 8, 9, 10, 11, and 12, from table on p. 117.

*Product of hydraulic cement in the United States.**

	Works.	1890.		1891.	
		Barrels.	Value.	Barrels.	Value.
Georgia	1	40,000	$ 40,000	40,000	$ 40,000
Illinois, Utica and La Salle	2	368,117	292,784	409,877	276,931
Indiana and Kentucky (Louisville region)	11	1,533,579	1,150,184	1,513,009	988,456
Kansas and Missouri (Kansas City and Fort Scott)	2	175,000	122,500	135,000	94,000
Maryland, Hagerstown, Cumberland, and Hancock	8	223,209	203,785	204,900	187,855
Minnesota, Mankato	1	87,650	65,737	101,875	76,406
New York, Onondaga county	8	281,086	183,268	288,941	188,944
New York, Ulster county	17	2,683,579	2,213,962	2,815,010	2,252,008
New York, Schoharie county	1	25,357	20,286	27,055	21,644
New York, Buffalo and Akron	4	765,734	560,277	788,300	575,288
Ohio, Bellaire and New Lisbon	2	57,000	56,000	70,000	68,000
Pennsylvania (Lehigh Valley)	6	555,000	484,900	695,000	586,600
Tennessee, Chattanooga	1	48,423	48,540	33,100	36,026
Utah, Salt Lake City	1	....	....	5,000	10,000
Virginia and West Virginia	2	20,000	15,000	20,000	15,000
Wisconsin, Milwaukee	1	450,000	180,000	460,000	150,000
Total	63	7,308,734	$5,582,243	7,607,067	$5,512,153

Notes on the distribution of the magnesian limestones.—No attempt has been made by the Survey to ascertain the details of the distribution of the magnesian limestones, and the facts here given are only such as have been gathered incidentally in connection with the work on marble and zinc. The magnesian limestones are widespread throughout the greater part of the Silurian area shown on the map sheets accompanying this report. They occur in several beds separated by beds of chert and sandstone. In most places along the southern part of the Silurian area, the St. Clair marble and Izard limestone in the east, and the saccharoidal sandstone on the west, occupy a large part of the Silurian area, and even where the magnesian limestone occurs with those rocks, it frequently contains too much silica to be regarded as a limestone. It is chiefly in the northern part of the Silurian area that the stone approximates to a true dolomite, and has those qualities which give it value and economic importance.

It outcrops in the eastern part of Benton county along White River and its tributaries, where some good building stone occurs, but a large part of it is too siliceous for such

*Published in Mineral Resources, U. S., for 1889-90, p. 461.

use. As already stated, it occurs in quantity at a number of places along the Eureka Springs Railway. A fine quality of it is exposed in the King's River valley east of Eureka Springs and north of Berryville, and a small quantity has been quarried on the hill west of Jackson's store in 20 N., 25 W., section 5. It also occurs in the valleys of Osage Creek and King's River for many miles above the confluence of those streams.

The magnesian limestone outcrops on Long Creek, Carroll county, near the state line. It occurs in large quantities on all the tributaries of White River which flow from the south between Long Creek and Crooked Creek. While a great deal of it is siliceous, an abundance of fine building stone occurs along Bear, Upper and Lower Sugar Orchard, Music, Sister's, and Jimmy's Creeks. On lower Crooked Creek, from Harrison to the mouth, are vast quantities of beautiful building stone among the magnesian limestones, especially in the vicinity of Yellville and Powell. About one mile south of Powell on the west side of Clear Creek is an outcrop of a fine quality of the buff-colored dolomite. Most of that observed along the north side of Crooked Creek is light gray in color.

In the Buffalo River valley magnesian limestone outcrops in large quantities from Tomahawk Creek to White River, and also in another area from Richland Creek, Searcy county, to the confluence of Big and Little Buffalo Rivers, the largest exposure being in Stair Gap bluff at the mouth of Buffalo River. Stair Gap bluff is 600 feet high, and is composed chiefly of magnesian limestones which outcrop with a thickness of several hundred feet as far west as Rush Creek.

Below the mouth of Buffalo River the magnesian limestones outcrop abundantly on both sides of White River as far as Round Bottom (15 N., 10 W.), and on the north side of the river as far as Rocky Bayou. The finest exposure observed is in the bluff below the mouth of Rappied Branch (in 18 N., 13 W., sections 25 and 36; and 18 N., 12 W., section 31), where the stone is in regular layers from two to four feet thick. The rock is here a dolomite in composition, containing 48.23 per cent. of lime carbonate and 38.36 per cent. of magnesia car-

bonate; is light gray in color, homogeneous, and soft enough to be easily cut and carved with a penknife, yet its fine crystalline texture renders it capable of a fine, beautiful finish. It is so close to White River, which is navigable nearly all the year, that it could readily be quarried for shipping outside the state.

The section exposed on the road from Denton's Ferry to Gassville contains several beds of magnesian limestone, one eight feet thick, another twenty feet, and another forty feet thick. The same beds are exposed in the bluffs on the river half a mile above the ferry.

The magnesian limestone covers more or less of all that part of the State of Arkansas lying north of the area mapped in this report. That it underlies some of the Carboniferous area south of any Silurian exposures is shown by the record of the deep well at Fayetteville.*

*See report on Benton county, Vol. II., 1891.

CHAPTER IX.

Carboniferous Limestones on the South Side of the Boston Mountains.*

By J. H. Means, M. A., Assistant Geologist.

The exposures of Carboniferous limestones described in this chapter are the most important ones in Arkansas south of the Boston Mountains, but there are doubtless a few other small ones that have not been seen by the Survey.

The mass of the Boston Mountains is made up of approximately horizontal beds of sandstone and shale belonging to the Lower Coal Measures. On the north face of the mountains the strata are cut off abruptly by erosion and the section exposed extends from these sandstones and shales which form the summit of the mountains down through the limestones, shales, and sandstones of the Lower Carboniferous. Passing from north to south across the mountain range the horizontality of the strata is not greatly disturbed until the south face of the mountains is reached. Here, however, the rocks have been sharply bent and plunge beneath the sandstones and shales of the valley of the Arkansas River. Where the change of dip takes place erosion has cut deeply into the axis of the monocline and exposed the Lower Carboniferous limestones which are the stratigraphic equivalents of those exposed on the north face of the Boston Mountains. The thickness of the shales and sandstones of the Lower Coal Measures in the Boston Mountains proper varies fron 500 to 1500 feet. The beds thin out somewhat eastward, while toward the west they are more constant. South of the Arkansas River the limestones do not appear again within the Carboniferous region except in a few small local areas. One of these is in the Fourche la Fave valley near Boles, in the southern part of

*For further details on the geologic structure of this region see this Survey's report on the Lower Coal Measures by J. H. Means.

Scott county, 2 N., 29 W., section 36, near the center of the southwest quarter, and also in 1 N., 28 W., section 5, northwest quarter. In both of these exposures the strata dip at a very steep angle toward the south. The limestone beds exposed are about ten feet thick, and are rather impure in quality.

The limestones on the south side of the Boston Mountains have the same lithologic characteristics as those on the north, with the possible exception that they seem to be somewhat more siliceous. In some cases they thin out southward.

No attempt has been made from paleontological evidence to make a detailed correlation of the limestones on the two sides of the mountain. It is quite apparent, however, from their relations to the overlying rocks, from a casual examination of their fossils, and from their lithologic characters, that their occurrence south of the mountains is a continuation of the beds which outcrop on the north side, and described as the Kessler, Pentremital, and Archimedes limestones.* No attempt will be made here to distinguish these separate formations, but they will be spoken of simply as Lower Carboniferous limestones.

For the most part limestone occurs south of the principal range of the Boston Mountains only in the deepest valleys and ravines, where the streams have eroded the overlying shales and sandstones, leaving the underlying strata exposed. It is exposed therefore in isolated areas which are generally separated by high mountain spurs of shales and sandstones of the Lower Coal Measures. Near the west line of the state, however, it occurs higher up the mountain sides and its exposures are more continuous, owing to the greater erosion of that portion of the range and to the fact that the rocks rise gently toward the northwest.

LOCAL DETAILS.

Mountain Fork of Lee's Creek.—Starting at the west line of the state and proceeding eastward along the south side of the principal range of the Boston Mountains, the first locality where limestone occurs is in the valley of the Mountain Fork

*Annual Report of the Geological Survey of Arkansas for 1888, Vol. IV., Washington county.

of Lee's Creek. It forms a conspicuous escarpment on both sides of the valley at the mouth of Indian Creek, in 12 N., 33 W., section 26, and along the creek to its head. Above the mouth of Indian Creek it dips from 1° to 2° toward the southeast, but immediately below the mouth of Indian Creek near the southeast corner of section 26, the dip is much steeper and the limestone disappears beneath the overlying sandstones and shales. It occurs also in the base of a bluff, on the south side of Mountain Fork near the half-mile corner on the east line of section 36, but here again it disappears beneath the south dipping sandstone; below this point the general south dip of the rocks carries the limestone deep below the surface, and it does not appear again south of this point.

Cove Creek.—After leaving the Mountain Fork of Lee's Creek and its tributaries, the next exposure of limestone to the east is in the valley of Cove Creek. In 12 N., 32 W., section 9, the southwest quarter, the limestone forms a bluff on the west bank of the creek, dips south at an angle of 5°, and disappears beneath the overlying sandstones and shales. This point is the southern limit of the limestone observed in the valley of Cove Creek. About a quarter of a mile down Cove Creek from the southern limit of the limestone the sandstones dip south at an angle of 20°. Up the creek, however, the limestone continues to outcrop to the head of the stream in 14 N., 32 W., section 13; along the entire exposure the rocks have a general south dip approximately equal to the fall of the creek. There seems to be a local disturbance, however, and probably a displacement of the rocks in 13 N., 32 W., section 23, where the strata suddenly dip 12° southward and the limestones disappear beneath the overlying rocks, but reappear within less than a quarter of a mile down stream. Prof. F. W. Simonds mentions the occurrence of a fault at this locality.* In some places the limestone in Cove Creek valley forms naked bluffs on both sides of the creek; at others it is concealed beneath soil or debris on the more gentle slopes. The general dip of the rocks is toward the southeast, and the beds exposed

*Annual Report of the Geological Survey of Arkansas for 1888, Vol. IV., p. 117

are therefore higher on the west side of the creek than on the east side. Prof. Simonds gives the following section of the strata on Cove Creek at Morrow's coal bank in 14 N., 32 W., section 36.*

Section at Morrow's coal bank, Cove Creek.

	Feet.
Sandstone	120
Kessler limestone	10
Coal-bearing shale	61
Pentremital limestone	70
Washington shale and sandstone	95
Archimedes limestone	30
Shales	....

The following is the section at Oil Spring in 14 N., 32 W., section 24.†

Section at Oil Spring, Cove Creek.

	Feet.
Shale	10
Limestone	30
Sandstone	10
Shale	6
Oil-bearing sandstone	50
Black shale	10
Limestone at base of section	....

The limestones outcrop on the tributaries of Cove Creek as well as along the main stream, Garrett's Creek, in 13 N., 32 W., being the largest tributary on which it occurs. In section 21 of the same township and range is a flexure similar to that on Cove Creek, the rock dipping south in one place at an angle of 12°, while north of this point they are approximately horizontal. Limestones occur also on Fly Creek and on other small tributaries of Cove Creek.

Fall Creek.—Limestone was observed in but one place on Fall Creek, and that only in a very limited area, at the bend of the creek in 13 N., 32 W., section 36, the northeast quarter. The shales and sandstones dip southeast at an angle of 5°, and

*Annual Report of the Geological Survey of Arkansas for 1888, Vol. IV., p. 141.
†Ibid, p. 128.

the limestone disappears beneath them. The coal-bearing shales overlie the limestone and outcrop for some distance up the stream above the exposure of limestone.

Lee's Creek.—Limestone occurs on Lee's Creek in 13 N., 31 W., as far south as the south line of the township, which is the southern border of Washington county, where it disappears beneath the overlying shales which here dip south at an angle of 3°. The limestones, where exposed to the weather, are light gray, but where they have been struck in sinking a well at the southern limit of the exposure on Lee's Creek, they are of a dark bluish gray color. The bed struck in the well is 15 feet thick and underlies the coal-bearing shales. The limestones were observed as far up the creek as the north line of 13 N., 31 W., where they are concealed by the overlying shales. There is, however, a slight depression of the strata near the northwest corner of section 25, where the limestones are not shown at the surface and the massive sandstones which overlie the coal-bearing shales come down near the bed of the stream.

Blackburn's Fork.—On Blackburn's Fork of Lee's Creek limestone outcrops in 13 N., 31 W., sections 35 and 36, and continues up the creek into 13 N., 30 W., section 30, the southwest quarter, where it underlies the coal-bearing shale. At the upper limit of the limestones on the creek, the strata dip 5° north; at the down-stream limit they dip 3° to the south.

The limestone outcrops in 12 N., 30 W., in section 9, northwest quarter, and in section 4, southwest quarter, on a small tributary of Howard's Creek, into which it flows at Walker's Switch in section 16, same township. It outcrops on both sides of the brook and dips 5° south at the southern limit of the exposure, while farther north, in section 4, it is approximately horizontal.

An exposure of limestone occurs on Howard's Creek, above Porter, on the St. Louis & San Francisco Railway in 12 N., 30 W. It outcrops in a ravine at the south line of section 1, near the half-mile corner, and extends around the point of the hills at the mouth of the ravine and up Howard's Creek nearly to

the north line of section 2, where it disappears beneath the overlying sandstones. It is also exposed in the railway cut west of the creek near the south line of section 2, and disappears in the north half of section 11 beneath the overlying sandstones, which dip 5° southward. The limestone is about 20 feet thick and very impure, grading into a calcareous sandstone.

Little Frog Bayou.—In the valley of Little Frog Bayou limestone outcrops in 13 N., 29 W., section 28, the northeast quarter; the same bed has been struck eighteen feet below the surface in sinking a well one mile further up the creek. It extends down the creek to within about half a mile of its mouth, where it disappears with a dip of 5° to the south. At the north line of 12 N., 29 W., limestone extends nearly one mile up the stream, which flows into Little Frog Bayou from the west; it is not everywhere visible, however, as it is covered in places by surface debris.

Big Frog Bayou.—On Big Frog Bayou the limestone occurs a quarter of a mile above its confluence with Little Frog Bayou, and extends up the creek into 13 N., 29 W., section 31, near the center of the section, and up a north tributary to the center of section 30, same township. The outcrop on Big Frog Bayou is also largely concealed by talus, and its presence in many places can only be determined by its stratigraphic position.

Salt Creek.—Limestone outcrops on Salt Creek, a tributary of Mulberry River, in 12 N., 28 W., section 26, the northwest quarter. The bed here exposed is rather massive, and near the north line of the section it disappears beneath the overlying sandstones with a south dip of 5°. It extends two miles or more up the creek above this point, probably to the north line of section 23; the outcrop is rather obscured, however, toward its up-stream limit by talus from the overlying shales and sandstone.

Spirits Creek.—A limited exposure of limestone occurs on Spirits Creek, a small tributary of Mulberry River, in 12 N., 28 W., section 36, near its south line. The exposure is near

the stream, up which it extends about a quarter of a mile. At its southern limit it disappears beneath the overlying shales and flaggy sandstones with a south dip of 10°.

Fane's Creek.—More extensive exposures of limestone occur in 12 N., 27 W., on Fane's Creek, which flows into Mulberry River from the north. The down-stream limit of this exposure is in section 23, southeast quarter of the northeast quarter, where it disappears beneath the overlying shales, dipping south 20° east at an angle of 15°. It extends up the north prong of the creek into section 2, southeast quarter; up the west prong into section 20, northeast quarter; and up Lindsley's Branch into section 12, southwest quarter, same township. In all these outcrops along the north prong of Fane's Creek there are two beds of limestone separated by about 40 feet of shales and thin-bedded sandstones. The upper bed of limestone is about seven feet thick, the lower one about twenty feet thick. It is a gray earthy rock, and very shelly in character.

Mountain Creek.—In 12 N., 26 W., limestone outcrops on Mountain, Herod's, and Indian Creeks, all of which are tributaries of Mulberry River, entering it from the north. On Mountain Creek the down-stream limit of the limestone exposure on the main stream is in section 17, the southwest quarter, where it disappears beneath the sandstone, dipping south at an angle of 12°. Its up-stream limit on the east prong is in section 4, the southwest quarter; on the west prong, it is at the south line of section 6. It also occurs on a small tributary of Mountain Creek in section 18, the southeast quarter, and in section 19, the northeast quarter, near Cass post-office. The limestone, interbedded with the layers of sandstone, thins out southward, and at the same time becomes more shaly and siliceous where it disappears beneath the sandstone, dipping 12° to 15° south.

Herod's Creek.—On Herod's Creek, in 12 N., 26 W., section 3, there is an exposure of limestone high up the slopes of the mountain, but it descends abruptly toward the south until it disappears in the bed of the stream in section 10, southwest quarter, near the south line of the section, where the beds dip

south 5°. From the mountain slopes in section 3 the same rocks are exposed in horizontal beds up the narrow valley into 13 N., 26 W., section 34, the north half, where the last of the up-stream exposures are seen.

Indian Creek.—A shaly siliceous limestone occurs on Indian Creek from section 13, the northwest quarter, up the stream into 13 N., 36 W., the north line of section 36. It is mostly concealed by debris, only isolated places being exposed.

Limited exposures of limestone occur in 13 N., 25 W. It outcrops near the south line of section 34, near a brook tributary to Little Mulberry or Davis Fork. It also occurs in the north bank of Davis Fork beneath the massive bed of sandstone which forms a bluff at the south line of section 35, same township, where the rocks dip 5° south, and form the southern limit of the limestone exposure.

North Prong of Mulberry River.—Limestone is exposed on the North Prong of Mulberry River in 12 N., 24 W., section 11, the north half, where it dips 5° south. It continues up the creek into 13 N., 24 W., section 25.

Though limestone outcrops on many of the northern tributaries of Mulberry River, it has not been observed in the valley of that river itself; this is due to the fact that the general course of the stream is a little south of west, parallel to and nearly on the axis of the great fold which is more or less common along the south face of the Boston Mountains. The limestones therefore have a south dip on the north side of the river, and plunge beneath its valley.

Limestone Valley.—East of the head of Mulberry River is a high divide, composed of massive sandstone and shales of the Lower Coal Measures; these rocks overlie Carboniferous limestones. East of this divide is an extensive exposure of limestone on Piney Creek and its northern tributaries in 13 N., 21 and 22 W., where the valley broadens to form what is known as "Limestone Valley." The limestone outcrops in a bluff along the north side of the valley, receding up the steep-sided ravines on the north toward their source. The limestone was not observed south of Piney Creek in Limestone Valley, the

nearest approach to it being a calcareous sandstone which outcrops in a bluff at the edge of the water in 13 N., 23 W., section 14. On the north side of the valley the limestone occurs up-stream as far as the center of section 15, same township, and it extends up Home Creek to the center of section 1. It also occurs on Walnut Fork, in 13 N., 23 W., as far south as section 8, northwest quarter, and continues up the stream into 14 N., 22 W., section 33, northwest quarter. In 13 N., 21 W., there is limestone in the valley of Dry Fork from the mouth of the stream northward to near the center of section 6, and on its eastern prong to the center of section 5. It occurs also on Wet Fork of Piney Creek as far north as the center of section 3. Near the northern limit of the limestone exposures adjacent to Limestone Valley, the rocks lie approximately horizontal, but further south they have a south dip of from 7° to 10°, causing the limestones to disappear beneath the overlying shales and sandstones alońg the south border of the valley in 13 N., 22 W. They are also exposed farther down the creek in section 36, the same township, but to only a limited extent. They appear on Piney Creek in 12 N., 21 W., section 28, northeast quarter, near the south line of which the rocks finally disappear with a south dip of 3°.

Limestones occur on Hurricane Creek, in 13 N., 20 W., section 19, near the center of the section, and extend up the west prong of the creek through section 18 and into 13 N., 21 W., as far as the north line of section 13.

In proceeding eastward from the limestone exposures on Piney Creek and its tributaries, numerous ravines and narrow valleys are crossed between the projecting mountain spurs, but no limestones occur in them until the Middle Fork of Little Red River is reached in the southern part of Searcy county. In some instances, however, the streams have cut nearly as low as the limestone horizon, as in the case of the large tributaries of the Illinois River.

Middle Fork of Little Red River.—The limestones are exposed on the Middle Fork of Little Red River as far up-stream as 13 N., 16 W., section 17. It extends down-stream as far as

14 N., 15 W., section 35, south half, which is about a quarter of a mile below the mouth of Wiley's Creek. The limestones outcrop at the base of the hills on both sides of the valley, and by their disintegration the narrow bottoms along the river are constantly supplied with lime, which perpetuates their fertility.

Wiley's Cove.—There are extensive exposures of limestone in Wiley's Cove in 14 N., 15 W. Near the mouth of Wiley's Creek the exposure is near the base of the hills only, but farther north in the cove the limestone is at a much higher level above the watercourses, occurring in the bluffs on both sides of the cove. Toward the north the beds are approximately horizontal; toward the southern limit of the exposures they dip about 3° southward and disappear beneath the overlying shales and sandstones. Dr. D. D. Owen visited Wiley's Cove in 1857 and noted the occurrence of limestone, of which he gave the following section :*

"1. Archimedes limestones.

"2. Encrinital, and Chonetes limestones, alternating with thin shaly partings.

"3. Black, brittle, bituminous limestone, or marble rock.

"4. Black, bituminous, hard, sheety shale."

The fragments of chert along the watercourses of Wiley's Cove have weathered from the limestone beds.

Owl's Cove.—Large fragments of reddish crystalline limestone were observed by assistant J. F. Newsom in Owl's Cove on the slope of the mountain in 13 N., 14 W., section 5, the southeast quarter. The bed from which the fragments come is concealed by debris from the overlying rocks.

Mr. Newsom also observed fragments of limestone in a ravine in 11 N., 12 W., section 14, the east half, but the bed from which they came was not found in place. He also observed a bed of limestone in the slope of the hill immediately north of the public road in 7 N., 16 W., section 10, the northeast quarter, and about 150 yards west of the iron bridge over Point Remove Creek. This bed of limestone is siliceous and

*First Report of a Geological Reconnoissance of Arkansas, by D. D. Owen, p. 77.

contains fragments of fossils. Its greatest thickness where exposed is about 2½ feet.

Uses.—There is practically no demand at present for the limestones mentioned in this chapter except for lime making. Lime has been burned in several of the localities mentioned, but generally to a very limited extent, as there is no market for it and it is used only to supply local demands. The majority of localities where limestone occurs are too far from railway or other transportation facilities to make shipping the lime to the city markets profitable. The only exposures of limestone accessible to the railway south of the Boston Mountains are those in 12 N., 30 W., near Porter Station and Ward's Switch, on the St. Louis & San Francisco Railway.

The limestone near Boles in Scott county is the only limestone that occurs in quantity in the Carboniferous belt south of the Arkansas River; it is therefore valuable as a source of supply of lime for a large area of the surrounding country. But little lime has been burned at this place, however, as the demand for it in the country is as yet quite limited.

The limestones on the south side of the Boston Mountains, and in the southern part of Scott county, are surrounded by regions whose soils are derived entirely from sandstones and shales, rocks which contain scarcely any lime. These limestone exposures might, therefore, be turned to account as sources of lime to be used as a fertilizer. No effort has yet been made, however, so far as the Survey has been able to learn, to utilize the limestones in that way.

CHAPTER X.

Other Limestones in the State.

THE TRINITY LIMESTONE.

In the southwest part of the state, in Pike, Howard, and Sevier counties, along the northern border of the Lower Cretaceous area, is an outcrop of limestone, designated by Prof. Robert T. Hill of the Survey, as the Trinity limestone, and described by him as follows: "In general, it is a series of calcareous, gypsiferous, argillaceous sands, alternating with numerous thin strata of firm yellow crystalline bands of limestone, which vary from one inch to one foot in thickness.

"The grayish yellow limestone strata are usually persistent in extent, firm, ringing under the hammer's blow, often crystalline, and differing from most of the overlying cretaceous beds in that they were originally composed almost entirely of small littoral shells, which can be seen in some places where the brecciate structure of the rock is as well preserved as that of the "coquina" or shell rock now in process of formation on the Florida coast. Generally, however, the shell structure has been dissolved and replaced by crystallized calcite. Upon exposure the hard rocks generally exfoliate into thin fissile slabs, their surface often exhibiting ripple marks. The limestones and marls of the Trinity are never glauconitic or chalky as are those of the upper cretaceous series, nor have they the massive, flinty and decomposing character of the Comanche series, while the contained fossils are of entirely different species. The sands or sandy strata, although they constitute the bulk of this division, owing to loss of structure under atmospheric alteration and dense forest growth, are seldom noticeable, except in recently formed gulches.

"The limestone beds of the Trinity formation are highly fossiliferous, and the shells which belong to but few genera

and species, occur in the greatest profusion. Slabs of the limestone are sometimes perfect masses of minute shells, consisting mostly of *Anomia*, *Corbicula*, *Lucina*, *Ostrea*, and *Pleurocera*. The sands are, also, fossiliferous, but in them only the casts are preserved, which, owing to the excess of pyrites almost immediately lose their identity upon exposure.

"Although the area of this formation is seldom more than two miles in width, it has great length, as may be seen upon the map, appearing only in the great east and west valley, from which the gravel plateau has been denuded."*

CRETACEOUS CHALK.†

In the Cretaceous area in the southern part of the state there occur heavy beds of chalk and marl, interspersed with sands and clays. There are three localities where the exposures of the chalk indicate a deposit of great commercial value: White Cliffs Landing, 11 S., 29 W.; Rocky Comfort, 12 S., 32 W., both in Little River county; and Saline Landing, west of Saratoga, in 11 N., 28 W., in Howard county.

The White Cliffs chalk.—Of the White Cliffs chalk Prof. Hill says:‡ "Descending from the post-tertiary gravel capped plateau into the valley of Little River the foregoing clay marls can be found resting upon, or changing into a great bed of the purest white chalk, at the bluffs of Little River, section 35, 11 S., 29 W. These cliffs, which have long been a landmark of the region, are about 150 feet in height, perpendicular, and as white and almost as pure as the celebrated chalk cliffs of Dover, England. Their remoteness from the lines of travel is the probable explanation of their having so long been overlooked by American geologists.

"The chalk of these cliffs scales off rapidly in great conchoidal flakes, and, owing to the irregularity of this process, its face, instead of being a continuous plane, is composed of

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*Annual Report of the Geological Survey of Arkansas for 1888, Vol. II., p. 117.

†The Cretaceous area, including the chalk areas, are described in detail by Prof. Robert T. Hill in the Annual Report of the Geological Survey of Arkansas for 1888, Vol. II. The volume is accompanied by a map of the area.

‡Op. cit., pp. 87–88.

many acute and re-entrant angles, resembling the bastions of a fortress. The summit of the cliff is covered with gravel, but measuring from the top of the hill a short distance from the margin, the present thickness of this chalk is found to be about 135 feet from the summit to the bed underlying it. This chalk has a low southeastern dip.

"The regularity of this bed throughout its exposure—about one-fourth of a mile—and its reappearance a few miles to the east and across the Saline watershed, shows that it is not a local bed, but the remnant of a great and extensive horizon worn away by the denudation through tertiary and quaternary times of the deposits of the Red River embayment. From the summit of this bluff one looks out over broad lowlands to the south and east which form the drainage basins of Little and Red Rivers, and over which this chalk bed once extended. These topographic features together with the overlying quaternary gravel beds and present disintegration speak most plainly of the great forces that have removed it.

"This chalk is almost free from fossils, but indistinct impressions of *Camptonectes*, *Inoceramus*, *Baculites* and other forms, are occasionally found.

"*The White Cliffs sub-chalk*.—The basal thirty feet of the cliffs are composed of an impure chalk, composed of glauconite and arenaceous grains, cemented by a calcareous matrix. This is full of the characteristic upper cretaceous fossils, *Inoceramus barabini*, *Baculites ovatus*, *Exogyra costata*, etc."

The Rocky Comfort chalk.—Speaking of the chalk at Rocky Comfort, Prof. Hill says:* "The rock of this formation is a massive, nearly pure, white chalk, usually free from grit, and easily carved with a pocket knife. Under the microscope it exhibits a few calcite crystals, and particles of amorphous calcite, and innumerable foraminiferæ. The air-dried, indurated surfaces are white, but the subterranean mass has a bluish white color. The rock weathers in large conchoidal flakes, with an earthy fracture.

"In composition it varies from 85–94 per cent. of calcium

*Ibid, p. 90.

carbonate, the residue consisting of magnesia, silica, and a small percentage of ferric oxide, as can be seen from the following analyses of unselected specimens by the chemist of the Survey:

	Texas.	Rocky Comfort.
Calcium carbonate	82.512	88.48
Silica and insoluble silicates	11.451	9.77
Ferric oxide, Alumina	3.648	1.25
Magnesia	1.189	trace

"The thickness of this chalk at Rocky Comfort is over 500 feet, 100 feet of which can be seen at the surface, the remaining 400 feet having been penetrated by bored wells. So far as observed in Texas it averages the same thickness at Austin, Sherman and Dallas. It is of great uniformity throughout its massive thickness and extent, but it shows a few local differences in hardness, which are sometimes due to surface induration."

The estimated area of this chalk exposed without covering about the village of Rocky Comfort, is 900 acres. At White Cliffs on Little River is an area of the same extent, much of which is covered with soil, gravel, and cobblestones, although but little of the covering is thick enough to seriously interfere with the handling of the chalk. At Saline Landing, in 11 S., 28 W., sections 35 and 36, there is an exposure of chalk 20 feet thick at the water's edge. There are only a few acres of the chalk uncovered at this place, but the structure and topography of the region and the records of deep wells, show that there is also a large area of chalk in the surrounding country. An artesian well sunk to a depth of 455 feet, about an eighth of a mile east of Saline Landing, passed through 140 feet of limestone, most of which is chalk. About three quarters of a mile northeast of the landing another well 388 feet deep had the upper 110 feet in the same chalky limestone. The chalk bed has a south dip of 3° or 4°.

Economic value of the chalk.—The value of this chalk for cement purposes is hardly appreciated at the present time.

When we consider that chalk is a very soft rock, and therefore does not require grinding as do the compact limestones, and further the greater ease with which it can be burnt to lime, its superiority over other limestones may be seen. The fact that this bed is the only one known to exist in the United States increases its value. The following analyses show how closely it agrees in composition with the chalk of Medway, England, which has so long been used in the manufacture of the famous Portland cement:*

	Medway, England.	Base of cliff, White Cliffs Landing.	Top of cliff, White Cliffs Landing.	Rocky Comfort.
Carbonate of lime......	88.58	88.74	90.32	88.48
Carbonate of magnesia .	....	trace	trace	
Silica..................	5.45	6.85	6.65	9.77†
Iron oxide	1.05	1.43	1 30	1.25
Alumina	2.82	2.41	2.01	
Alkalies	2.61	....	....	

TERTIARY LIMESTONES.

As compared with those of the Lower Carboniferous, the Tertiary limestones of the state are of but little importance. Their locations, however, sometimes give them local value, and for that reason the principal occurrences known are mentioned in this place. The descriptions are taken from the notes of the State Geologist, and of Mr. Gilbert D. Harris, Assistant Geologist.‡

In a general way the Tertiary rocks cover all of the State of Arkansas east of the St. Louis, Iron Mountain & Southern Railway. Limestones, however, are not abundant in these

*Silica and insoluble silicates.

†For further details, see chapter on The Manufacture of Portland Cement in the Annual Report of the Geological Survey of Arkansas for 1888, Vol. II., p. 291.

‡Mr. Harris' observations on the Tertiary geology of Arkansas are published in the Annual Report of the Geological Survey of Arkansas for 1892, Vol. II.

rocks, and the few exposures known are chiefly confined to the western border of the Tertiary area.

At Grand Glaise in Jackson county fossiliferous Tertiary limestones with some arenaceous layers are exposed in beds about 50 feet thick a few rods south of the railway station. Similar rocks are cut by the railway at many points between Grand Glaise and Bradford, the most southern exposure being about a mile and a half north of Bradford. These Tertiary limestones form a shelf or terrace, in places about half a mile wide, abutting uncomformably against the Carboniferous hills which form the country to the west.*

Limestone ledges outcrop in the cemetery at Russell Station on the St. Louis, Iron Mountain & Southern Railway. These fragments indicate the approximate border of the Tertiary beds, near which it is possible that considerable deposits of limestone may exist.

At Little Rock, Tertiary limestone is frequently found in sinking wells on Capitol Hill and in the southwestern part of the city. Limestone was formerly dug from the hillsides west and southwest of the penitentiary, and was used for making lime. The old pits from which the rock was taken are still visible, but the limestone is no longer used.

About a third of a mile north of the county hospital and west of the railway there was once a lime-kiln, near which limestone boulders were dug from the hillsides for lime making. East of the railway opposite the hospital a bed of compact limestone is exposed in the bed of a small stream. This same limestone was struck ten feet below the surface in digging the well at the hospital.

On Fourche Creek near Olsen Switch (1 S., 13 W., section 8, southeast quarter) is a bluff exposing eighteen feet of compact Tertiary limestone, which is the best rock in Pulaski county for making lime. An abandoned kiln is still standing by the side of the railway track near Olsen Switch, at which a good quality of building lime was formerly made.

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*Mr. Harris has identified the following fossils from these Tertiary beds: *Turritella mortoni*, *Ostrea* and *Cytherea*.

LIMESTONE IN THE NOVACULITE AREA.

"Some curbstones have been quarried from limestone beds nine miles northwest of Hot Springs; lime has been burned at the same locality. In several other localities within the novaculite area lime has been burned for local use. Lime burning at these localities has not always been successful. The beds are usually thin, rather impure, blue limestones, but in some localities, notably northwest of Cedar Glades on Buckner Creek, and near Blocher post-office, the beds reach a thickness of eighteen inches to two feet, and are sometimes crystalline to a large extent. The stone from these localities, and perhaps some others, might be used as building stone."*

A black crystalline limestone in lenticular masses, 6 to 8 inches thick, is reported to occur at Totten, 15 miles west of Little Rock. This and the limestones in the novaculite area of the state are all of Lower Silurian age.

Limestone in Magnet Cove.—In Magnet Cove, Hot Spring county, there are several outcrops of a coarsely crystalline limestone which forms in one place a bluff twenty or thirty feet high. In some places it is comparatively pure and in others it is filled with contact minerals. The stone is a loosely aggregated mass of large calcite crystals, from a quarter to a half an inch in diameter, interspersed with other minerals.†

GENERAL CONCLUSION.

It will thus be seen that while limestone is widely distributed in the state, all that is suitable for building purposes occurs north of the Boston Mountains, and all the rocks of any considerable importance for lime burning occur in the same place. The chalk beds of southwestern Arkansas are the only lime deposits south of the Boston Mountains which are likely to have any great commercial value.

*L. S. Griswold, in Annual Report of the Geological Survey of Arkansas for 1890, Vol. III., p. 390.

†Annual Report of the Geological Survey of Arkansas for 1890, Vol. II., p. 183.

CHAPTER XI.

The Lime Industry of Arkansas.

In spite of the abundance of limestone in Arkansas suitable for lime burning, the state imports lime instead of exporting it. This condition is no doubt due in large measure to lack of transportation facilities, and as the limestone region of North Arkansas becomes traversed by railways the burning of lime should become one of the most important industries. As may be seen from the preceding pages there are limestones in the Tertiary and Cretaceous areas of the central and southwestern portions of the state, yet the Paleozoic limestones of the north part of the state are so superior for lime burning that it is to them the state must look for its lime supply. The chalk beds will no doubt become valuable in the manufacture of Portland cement, but for common lime it cannot compete with the Paleozoic limestones.

While in North Arkansas there are not less than seven distinct beds of limestone persistent over large areas, and others of more limited extent, it is noteworthy that nearly all the lime that has been burnt has come from a single bed—the limestone in the Boone chert. It has a greater areal extent than any of the other beds, yet others of large extent would make equally as good lime. The explanation of the greater use of the chert limestone is that it is the only one that presents a good outcrop on a railway. On the following pages will be found a description of such lime industries as exist or have existed in the state, so far as known to the Survey. They will be spoken of under the head of the counties in which they have been established.

Independence county.—The largest lime producing point in Independence county at present (1892), in fact the largest in the state, is at Denieville, between Batesville and Cushman,

on the Batesville branch of the St. Louis, Iron Mountain & Southern Railway. The business was established in 1887, since which time the output has been as follows:

Lime produced at the Denieville lime-kiln.

	Barrels.	Cost at kiln.	
Daily capacity of the kiln	80 to 100		
Output for year 1887 (6 months)	15,000		
Output for year 1888 (7 months)	17,000		
Output for year 1889 (10 months)	24,000	70c bulk,	90c barreled
Output for year 1890 (9 months)	18,000	60c bulk,	80c barreled
Output for year 1891	20,000	60c bulk,	80c barreled
Output for year 1892 (6 months)	23,000	60c bulk,	80c barreled

Previous to 1891 the lime was burnt in a stone kiln 25 feet deep and 5.5 feet in diameter, with a daily capacity of 90 barrels. In this kiln 5 to 5.5 cords of wood were required to burn 100 bushels of lime. In 1891 a new Monitor kiln (Sandusky, Ohio) was erected, which is of iron and has an internal diameter of 4 feet at the top, 6 feet at the bottom, and a depth of 30 feet exclusive of the stack and the cooler. The lime is drawn every three hours, while from the old kiln it was drawn every six hours. The advantages claimed for the Monitor over the stone kiln are:

1. Economy of fuel.
2. Purer lime. (The ashes are not mixed with the lime.)
3. Economy of labor. (The cooled lime can be drawn directly into the barrels.)

The owner expects to run both kilns in 1893.

The rock from which the lime is burnt is a fossiliferous crystalline limestone of the Boone chert formation (see p. 104); it has a face of 15 feet in the quarry and occurs in layers varying from 4 inches to 1 foot in thickness at the top of the quarry, and from 2 feet to 4 feet thick at the bottom. Some intercalary chert occurs in the upper part of the bed, where the limestone is also finer grained than at the bottom of the quarry. Analysis shows it to be a remarkably pure limestone.

Analysis of Denieville limestone.

Carbonate of lime	98.43 per cent.
Carbonate of magnesia	.95 per cent.
Insoluble residue	.28 per cent.

A large part of the lime is shipped to the company's office in Little Rock, but some of it is shipped to other points in central and southern Arkansas, and some to Louisiana and Texas. It is claimed that this quarry supplies about two thirds of the lime used in Little Rock, one third coming from Missouri and Tennessee.

The Allen quarry is two miles north of Batesville, on the east side of Polk Bayou, where an intermittent kiln was constructed many years ago, the exact date of which could not be ascertained further than that it was in operation in 1858*, nor is it known exactly how long it continued in operation. It is estimated that three or four thousand barrels of lime were burnt. The kiln is not now (1892) in operation. The stone is from the Boone chert and analysis shows it to contain 55.17 per cent. of lime or 98.29 per cent. of the carbonate of lime.

At the Jones quarry, 5 miles northeast of Batesville, in 14 N., 6 W., section 25, the northwest quarter, some lime has been burnt in an intermittent kiln, which was constructed about twenty years ago. It is estimated that about 3000 barrels of lime were burnt. The kiln is not now (1892) in operation. The limestone is in the Boone chert; analysis shows it to contain 53.65 per cent. of lime, or 95.82 per cent. of the carbonate of lime. Building stone has also been taken from this quarry (see p. 101).

On Mr. Pierce's farm, in 14 N., 5 W., section 30, an intermittent kiln was erected and a small quantity of lime burnt for local use.

Sharp county.—Hon. Sam. H. Davidson of Evening Shade, Sharp county, states that lime was burnt at Evening Shade for several years by Robert Gray, but in 1890 none was being made. Several kilns were burnt at King's Mills by James A. Nance, but the kiln was not in operation in 1890. The Ameri-

*Geol. Rec. of the Northern Counties of Ark., 1858, by D. D. Owen, p. 220.

can Zinc Company burnt large quantities near Calamine when the zinc mines were in operation at that place several years ago. Mr. R. W. Hall opened a kiln at Hardy in November, 1892, and in the last two months of that year burned 400 bushels of lime, which was sold at the kiln at 16⅔ cents per bushel. A kiln in the north part of the county is reported to the Survey to burn 1000 bushels per year, which sells for 10 cents per bushel at the kiln.

Boone county.—On the north bank of Crooked Creek, one mile east of Harrison, is a lime-kiln where lime has been burnt for use in Harrison. The rock used is from the St. Joe marble bed of the Boone chert series.

Carroll county.—A small quantity of lime was formerly burnt on the hill on the north side of Dairy Spring Hollow for use in Eureka Springs, but it was not in operation in 1891.

On Pond Mountain, three miles west of south from Eureka Springs, John Morehouse burns small quantities of lime for the Eureka Springs market. For the three years, 1890-92 inclusive, he reports 9000 bushels. The stone is obtained from the Boone chert and is very rich in lime, showing on analysis 55.06 per cent. of lime, equivalent to 98.32 per cent. of the carbonate of lime.

Benton county.—In a ravine about a quarter of a mile east of *Rogers* is a lime-kiln from which lime has been shipped to various points in the state. The kiln now in use is a stone one, 3.5x4 feet, and 24 feet deep. The bottom of the kiln is 130 feet below the railway at Rogers. The owner in March, 1892, reported the capacity of the kiln at 3000 bushels per month, and the price as 20 cents per bushel at the kiln. It requires two cords of wood to burn 100 bushels of lime. The stone is from the Boone chert; the largest face exposed in the quarry is eight feet, which contains from four to six inches of chert.*
Analysis shows it to contain 54.89 per cent. of lime, or 98.02 per cent. of carbonate of lime.

The lime, besides supplying the local trade, is shipped to Ft. Smith, Morrillton, Mansfield, and the Indian Territory.

*See Annual Report of this Survey, Vol. II., 1891.

One mile northwest of *Garfield*, on a tributary of Sugar Creek is a lime quarry, where considerable quantities of lime were burnt a few years ago. The kiln is on the north side of the creek and the quarry on the south side. A tramway was used to convey the stone from the quarry to the kiln, and another was used to transfer the lime from the kiln to the railway at Garfield. The limestone, which belongs to the Boone chert series, has a quarry face of forty to sixty feet with some intercalary and nodular chert. No analysis has been made of the limestone, but it probably varies but little from that at Rogers.

From February, 1884, to November, 1886, the quarry at Garfield was operated by Peel and Benn, who sold during that time 86,300 barrels of lime and fifty car-loads of lime in bulk. In 1887 the property came into the possession of H. S. Dean, who in 1887 and 1888 shipped 15,000 barrels of lime and a few car-loads in bulk. The principal points to which this lime was shipped are Ft. Smith, Van Buren, and Little Rock, Arkansas; and Wichita, Newton, Hutchinson, Dodge City, Emporia, Mulvane, Winfield, Wellington, Halstead, and a number of smaller towns in Kansas. The quarry, which now belongs to the heirs of H. S. Dean, has not been in operation since the fall of 1888.*

Washington county.—"Lime has been burned in several places in the county, both from the cherty and from the Archimedes limestone, as on the northern bluff of Baxter Mountain; at Mr. W. F. Dowell's, in the southwest quarter of section 29, in 16 N., 30 W.; in 16 N., 31 W., the northwest corner of section 1; in 14 N., 30 W., the southeast quarter of the northwest quarter of section 5, south of the village of West Fork; and in 17 N., 30 W., near the center of the south half of section 22. Only the kilns of the latter place were in operation in 1888, the others, with the possible exception of that at West Fork, having been long since abandoned. The rock burned is mostly taken from a quarry in the hillside above the northern

*For the statistical information on the Garfield lime quarry the Survey is indebted to Hon. J. B. Lamkin of Garfield.

kilns, where the rock shows a face 25 feet high. Although the beds are those of the cherty limestone, the rock is hard, of a gray color, and comparatively free from chert. The quarries above the southern kilns, however, show cherty layers from 2 to 6 inches thick, separating the layers of limestone which are of varying thickness, some being 18 inches or more. Much of the lime manufactured is shipped to Ft. Smith and elsewhere on the railway. The kilns and quarries are near the St. Louis & San Francisco Railway, and conveniently situated for shipping purposes."*

Mr. L. D. Middleton of Ft. Smith, who owned the kiln in 17 N., 30 W., section 22, for several years, states that the kiln was opened 10 or 12 years ago, but for the first five years only a few hundred bushels of lime were burnt for local use. About five years ago (1887?) a good draw kiln was built, and in the next three years 20,000 bushels or more of lime were burned and shipped to Ft. Smith, Van Buren, and other points on the St. Louis & San Francisco and the Little Rock & Ft. Smith Railways.

Mr. J. W. Carter, the present proprietor, gives the output of the kiln in 1891 as 20,000 bushels, and in 1892 as 35,000 or 40,000 bushels. He shipped lime to Ft. Smith, Van Buren, Clarksville, Rogers, Huntington, Jenny Lind, and other points in Arkansas; also to Tuscahoma, Muscogee, Eufaula, and Hartshorn in Indian Territory. The capacity of the kiln is given as 80 to 100 barrels in 24 hours.

Other points in Arkansas where lime has been burned.—At Little Rock in 1846 Mr. Hill, a hunter and trapper, engaged Mr. Whittemore to burn lime on the hill southwest of the penitentiary. How long the kiln was in operation or the amount burned is not known, but the supply was so small and the quality so poor that the industry was soon abandoned. The limestone used was of Tertiary age.

At Olsen Switch, on the St. Louis, Iron Mountain & Southern Railway, Mr. John Olsen erected a lime-kiln, and for two

*From the Report on Washington county, Annual Report of the Geological Survey of Arkansas for 1888, Vol. IV., p. 129.

years (1876–78) burned and shipped lime to Little Rock, Hope, Texarkana, and Texas. The capacity of the kiln was 500 barrels a week. Mr. Olsen's estimate of the total amount burnt in the two years is 10,000 barrels or more. The kiln has not been in operation since 1878.

The Survey is informed that a small quantity of lime was burned near Mountain Valley, Garland county, in 1890.

Lime has been burned on log-heaps for local use at White Cliffs Landing on Little River near Brownstown for more than 50 years. In 1870 a kiln was constructed and lime shipped to Shreveport, Louisiana, and to Little Rock and Texarkana, Arkansas. The kiln was in operation only two or three years. The lime was made of the chalk exposed in the bluffs at White Cliffs.*

It is a common practice among the farmers living in the limestone region in the northern part of the state to burn their own lime, which they do by piling the broken fragments on a large log-heap and firing the mass. This is a slow process and a great waste of fuel, but it is practiced only where land is being cleared and the farmers wish to get rid of large quantities of wood.

Comparative value of limestones for lime burning.—Without taking into account the proximity to transportation, the different beds of limestone considered solely in the light of their value for making lime would rank about as follows: 1. Izard limestone; 2. Boone chert limestone; 3. St. Joe marble; 4. St. Clair marble; 5. Archimedes limestone; 6. Pentremital limestone; 7. magnesian limestone. Besides these there are local occurrences of good limestone among the magnesian beds in the Silurian. The advantages for lime burning of the Izard limestone over the Boone chert are: (1) The ease with which it is broken; (2) its freedom from chert; (3) the greater ease of burning.

The St. Joe marble is properly a part of the Boone chert series, but it differs essentially from the gray limestones higher

*The Survey is indebted to Col. D. B. Coulter of Brownstown for information on the lime industry at White Cliffs.

in the series in being more compact and crystalline and in requiring more burning to reduce it.

The St. Clair marble makes a pure lime but its toughness makes it expensive to prepare for the kiln and its higher crystallization makes it hard to burn.

The Archimedes and Pentremital limestones are often too impure to make a valuable building lime, yet in many places good lime can be obtained from them, and in nearly all places they would make a lime good for fertilizing.

It is difficult to compare the magnesian limestone with the others, as its value depends on whether a magnesian lime is wanted. At present it is not much in favor in this country, although Prof. Newberry states that lime made from magnesian limestone is frequently better than that obtained from pure carbonate of lime, and he recommends the use of the Snowflake marble of New York for lime burning, which stone contains 54.62 per cent. carbonate of lime and 45.04 per cent. carbonate of magnesia, a nearly pure dolomite.

A good stone for lime occurs locally in the Silurian rocks, notably on Clear Creek, Searcy county, and at various points in Marion county.

While a good limestone is essential for profitably carrying on lime burning, an inferior stone may often be more desirable if it is near transportation facilities, fuel, or markets.

Fuel.—In the absence of coal the fuel for lime burning is limited to wood, which occurs in large quantities, and at present is delivered at the kilns for prices varying from $1.25 to $2 per cord.

Summary of lime product of Arkansas.

	Locality.	Year or years.	Barrels lime.
1.	Olsen Switch, Pulaski county	1876–1878	10,000
2.	Garfield, Benton county	1884–1888	108,300
3.	Denieville, Independence county	1887–1892	117,000
4.	Allen quarry, Independence county	?	4,000
5.	Jones quarry, Independence county	?	3,000
6.	Carter quarry, Washington county	1887–1892	32,000
7.	Hardy, Sharp county	1892	160

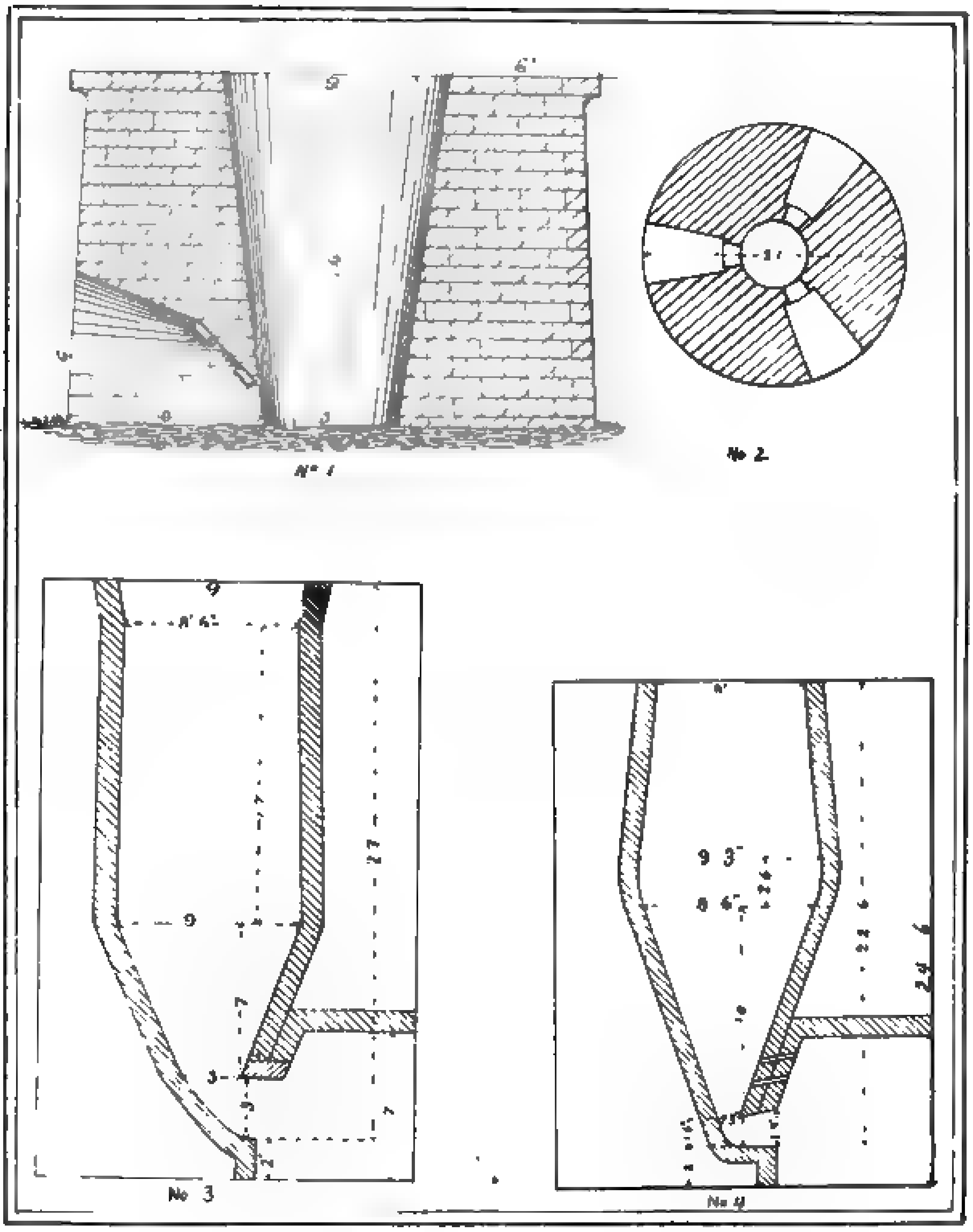
8.	Little Rock, Pulaski county	1846	not known
9.	Mountain Valley, Garland county	1890	not known
10.	White Cliffs Landing, Sevier county...........	1870	not known
11.	North part of Sharp county	....	
12.	Harrison, Boone county.....................	....	
13.	Eureka Springs, Carroll county...............	1890–1892	3,600
14.	Rogers, Benton county	....	
15.	Carter quarry, Washington county	previous to 1887	
16.	16 N., 30 W., section 29.....................	....	
17.	16 N., 31 W., section 1......................	....	
18.	14 N., 30 W., section 5	....	

LIME-KILNS.

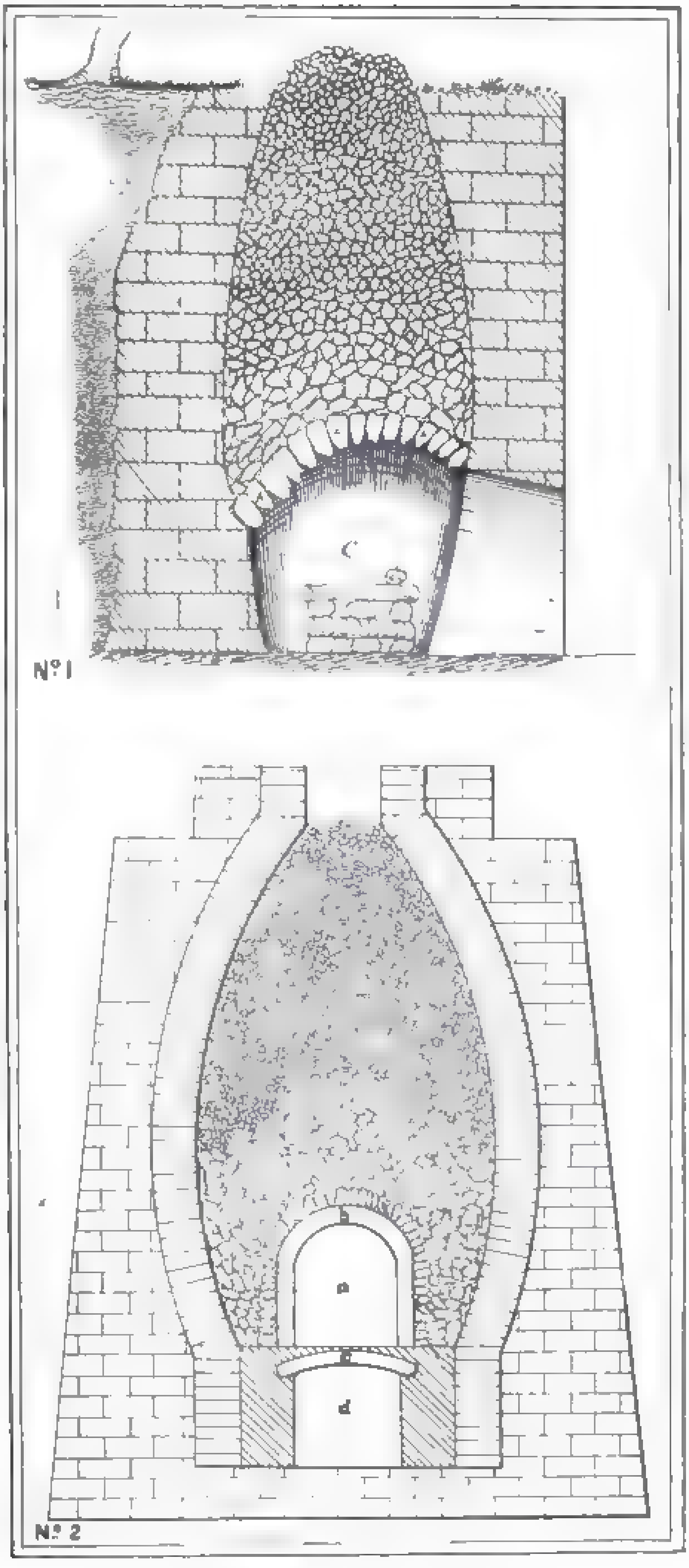
The kind of kiln used in lime burning depends upon the amount of lime to be burned and the amount of capital to be invested, and it often governs to a large extent the economy of the product.

The log-heap kiln.—The most primitive method of burning lime is that in which pieces of the rock are piled on a large log-heap and burned. This method is economical where the destruction of the wood is desirable, as in clearing the land, and where but a small quantity of lime is wanted. It is, however, necessarily restricted to the rural districts of heavily wooded regions.

The intermittent kiln.—One form of the intermittent kiln is shown in the illustration given in the upper figure in Plate V. It is generally of rubble or broken stone work without mortar, and, for convenience in charging, is usually built on a hillside. In filling it the largest stones to be burnt are formed into an arch AAA, on top of which the rest of the charge is placed, the larger pieces being thrown in first. The fire is kept up through the arched entrance C. With a kiln of this kind care must be taken to have the arch so constructed that it will support the overlying load of stone, and at the same time it must be open enough to permit the heat to pass through it. In firing, the heat must be raised gradually, as otherwise the arch rocks are liable to burst and the contents to tumble down, or many of the stones breaking into small pieces might pack together sufficiently to choke the draft.



PERPETUAL LIME KILNS.
No 1. Section of a common English kiln. No. 2. Plan of No. 1. No. 3. Common New York and Ohio kiln. No. 4. Common Maryland and Virginia kiln.



INTERMITTENT LIME-KILNS.
No. 1, Common masonry; limestone arch. No. 2, Lined with fire-brick; fire-brick arch.

A better form of the intermittent kiln is shown in the lower figure, on Plate V. The kiln is lined with fire-bricks, and the fireplace, *b*, rests on a permeated brick arch through which is a free circulation of air to secure the necessary draught. This arrangement obviates the breaking down of the kiln, which frequently happens with the first one. There are two serious objections to intermittent kilns: first, the stone in the lower part of the kiln is overburned before that in the upper part is burned enough; the other and chief objection is the great loss of heat, both in overburning some of the stone and in cooling the kiln to remove the lime. They are used economically, however, where the burning is not continuous, and where only a limited amount of lime is required to supply a local demand.

Perpetual kilns.—Perpetual kilns are intended to remedy the defects of the intermittent kilns, and in proportion as they do so their value increases. As the name indicates, they are kept burning continually, stopping only for repairs or in case of accident. There are two general classes of perpetual kilns: one in which the limestone and fuel are both added in proper proportions at the top of the kiln; the other in which the heat is applied from a furnace at the bottom and the limestone added at the top. In both forms the burnt lime is drawn periodically from the bottom of the kiln. There are many varieties of these two kinds of perpetual kilns, the differences being chiefly in the form of the interior. Most of those of the second class are patented.

No. 4, on Plate VI., shows a vertical section through the axis and draw pit of a kiln in common use in Maryland and Virginia; No. 3, Plate VI., shows the style preferred in New York and Ohio.* According to Gen. Gillmore, the kind of kiln in common use in Europe is shown in Nos. 1 and 2, on Plate VI., No. 1 showing a vertical section and No. 2 a horizontal section of the same. They are shaped on the interior like an inverted cone, are from 5 to 5.5 feet in diameter at the bottom, from 9 to 10 feet at the top, and from 13 to 14 feet high, or larger, and surrounded by a circular wall 20 to 21 feet in diameter, which

*Q. A. Gillmore on Limes, Hydraulic Cements ,and Mortars, p. 128.

has three openings in the bottom for the purpose of drawing the lime.

"A kiln of this form and of the dimensions indicated above, ought to yield about 500 cubic feet of quicklime every twenty-four hours, with a consumption of about two tons of coal."*

The three kilns above mentioned belong to the class in which the stone and fuel are mixed, starting with a layer of light wood covered with heavy wood or coal, and followed to the top by alternating layers of limestone and fuel. The kiln is fired at the bottom, and as the lime near the bottom is burnt it is withdrawn and fresh stone and fuel added at the top. In some places the drawing of the lime is done every half hour, in other places every six or eight hours. This style of kiln, while superior to the intermittent kiln, is far from perfection, and requires intelligent experience to run it successfully. Among the many defects in the process of lime burning due to ignorance and carelessness might be mentioned: neglecting to draw the burnt stone at the proper time; not preserving the proper proportion between the fuel and raw stone, hence over-burning the lime or only partially burning it, leaving more or less raw stone; irregularities in the settling of the stone at each drawing; making no allowance for changes in the rate of combustion due to the choking of the kiln, or the change in the direction and force of the wind, or barometric changes in the atmosphere, or for the difference in quality of the fuel used. Besides those mentioned there are defects in this process due to the process itself, one of which is overburning and under-burning, which, though injurious in all limes, is less so in common limes than in cement; another is the mixing of the ashes and cinders of the fuel with the lime.

*Q. A. Gillmore on Limes, Hydraulic Cements, and Mortars, p. 141.

The Page kiln.—Among the patent kilns constructed as improvements on the process described above, is the perpetual flame or furnace kiln, patented by C. D. Page of Rochester, N. Y.—a kiln which has had an extensive use in that state and elsewhere for burning both lime and cement. Figure 3 shows a vertical section of one of these kilns constructed for burning wood. The arrangement is a little different where coal is used for fuel.* In the kilns represented in the figure there are two furnaces; some are used with four, while others have as many as ten furnaces when coal is used for fuel. In the figure K is the crib at the top of the cupola, L and M are timbers to bind the wall together, Q the peek holes to watch the progress of the burning, T the furnaces, U the ash pits, and V the draw hole. Figure 4 shows a horizontal section of same kiln.

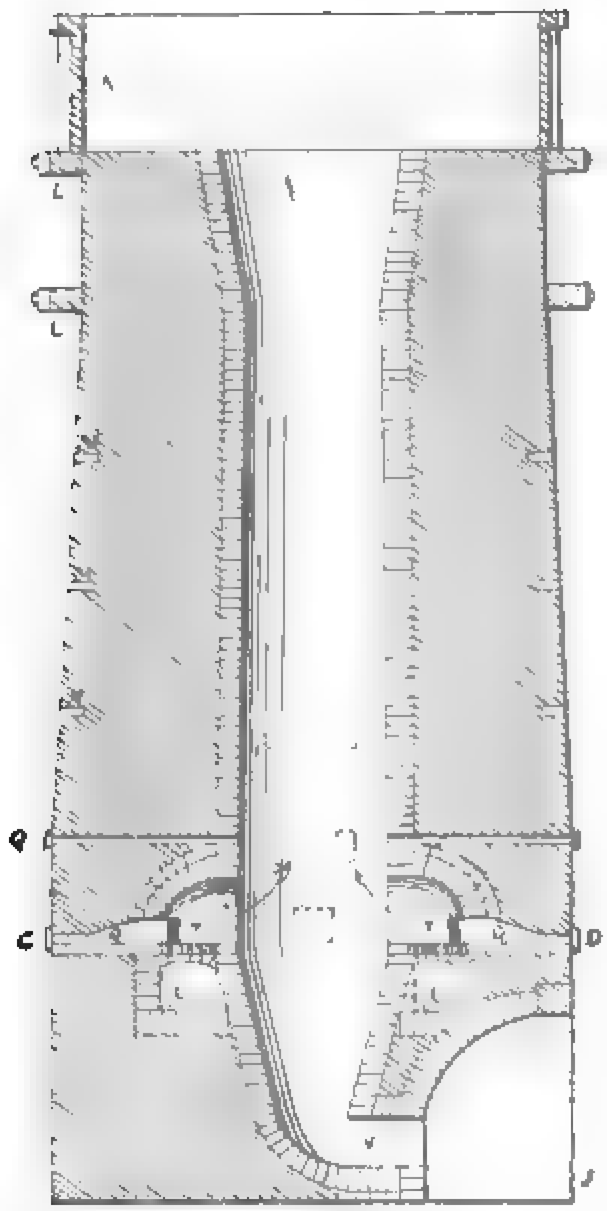


FIG. 3. *Vertical section of a Page flame kiln with two furnaces constructed for burning wood. (After Gillmore.)*

The Page kiln has been highly recommended by those using

*Q. A. Gillmore's Limes, Cements, and Mortars, pp. 134 and 135.

it. Its superiority over the ordinary draw kiln for cement burning was shown by a number of experiments made by the Newark and Rosendale Company of Whiteport, N. Y. An equal number of parallelopipedons were made from cement burned in the ordinary draw kiln and in Page's flame kiln; these blocks were broken with the following results:

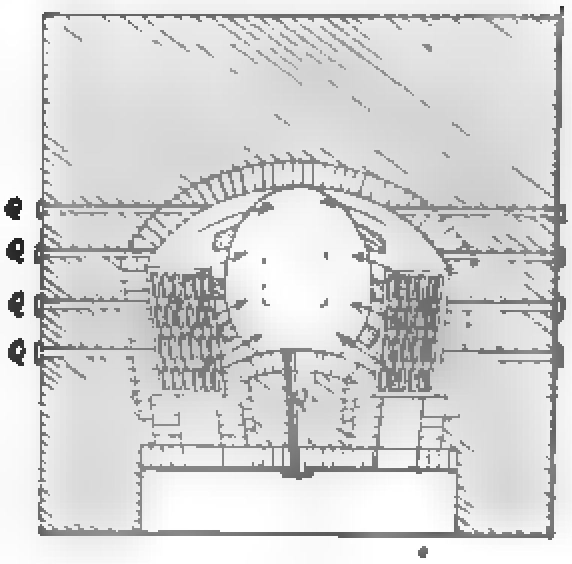


FIG. 4. *Horizontal section of a Page flame kiln.*

Average breaking weight in pounds of each kind of mortar.

	Pure cement (stiff paste). Pounds.	Dry cement 1 volume, sand 2 volumes (stiff mortar). Pounds.
Page flame kiln	499.50	313.64
Draw kiln......................	360.75	228.73*

The Hoffman kiln.—The Hoffman (German) kiln or ring oven is circular or elliptical in plan, consisting of a series of chambers arranged about a central chimney with which they are connected, each chamber also having means of communication with the adjoining chambers and with the outer air. The fuel is introduced through openings on top and the fire travels from one chamber to another. While the workmen are taking lime from one chamber, number 5, e. g., the communication between it and the adjoining chambers is closed; the lime in number 6 is cooling, and number 4 is being filled with raw stone. The chief advantages of this kiln are: (1) that the temperature is controlled throughout the process, which results in great saving of fuel and proper calcination; and (2) the work is all on the same level. While a chamber must be comparatively cool before the lime can be taken out, the heat is not dissipated, but much of it is utilized. The chief objection appears to come

*Q. A. Gillmore's Limes, Cements, and Mortars, p. 137.

from the necessity of working in the warm, dusty chambers.*

The Brock kiln.—The French or Brock kiln consists of a long horizontal channel built generally of fire-bricks, through which trucks laden with limestone are passed; the stone is burnt to lime on its passage. The chamber is divided into two parts by the platform of the trucks, which is supposed to be an air-tight partition; the burning is done in the upper one. The cast-iron platform of the trucks is covered with fire-bricks bedded in clay to keep the heat from the trucks underneath. The guides on each side, which run in a bed of sand, are designed for the same purpose.

The difficulties with this kiln are, to keep the trucks cool, and to prevent the stopping of the trucks by heated spindles or by the cinders and materials from the trucks clogging the guides. It overcomes the objection to the Hoffman kiln by bringing the material out of the closed chamber before it needs handling, and further, has it already on trucks for lading, thus saving extra handling.

Herr H. Dueberg of Berlin, Germany, claims to have invented a kiln which combines the good points of both the Hoffman and Brock, and eliminates their objectionable features. In this the materials are loaded on trucks similar to the Brock and run into chambers as in the Hoffman. In this way there is no handling in hot dusty chambers, and no moving a long line of hot trucks.†

Such kilns as the Hoffman and Brock are used only where lime is burnt on a large scale, but they are equally well adapted to the burning of cement and bricks, for which they are also used.

The lime kilns described above are representative of the different classes, from the crudest and cheapest to the most expensive. The kind of kiln to be used at any place should be governed by the amount and kind of lime to be burned. It would be as extravagant to erect an expensive kiln in which to

*For description of the Hertrampf kiln, an improved Hoffman, see Sci. Amer. Supp., No. 572.

†Sci. Amer. Supp., No. 148.

burn a small quantity of lime as it would be to waste time, labor and fuel trying to burn large quantities in an inferior kiln. To successfully burn hydraulic lime or cement requires a kiln in which the operator can have control of the temperature, hence a common kiln is rarely used for this purpose.

With proper transportation facilities, there is no apparent reason why the upper White River Valley should not supply all the south part of the Mississippi Valley with lime, as it contains limestone of excellent quality and sufficient quantity, with abundance of wood for its reduction.

PART II.—MARBLE.

CHAPTER XII.

The Origin and Uses of Marble.

Any limestone, whether compact, crystalline, or granular, which will receive a polish and is suitable for ornamental purposes, is considered a marble. Marble, however, is a commercial rather than a scientific term, and for this reason its use cannot be confined to the crystalline or metamorphic limestones, as some writers are inclined to restrict it.* Other ornamental stones, such as serpentine, porphyry, alabaster,† etc., are sometimes, though improperly, spoken of as marble, but these are misapplications of the term to stones which are sufficiently characterized mineralogically and lithologically by their names.

While there is an almost endless variety of marbles they are all varieties of limestone, and all that has been said in a general way of the limestones is applicable to the marbles.

METAMORPHISM.

The stalagmitic or onyx marbles are deposited in a crystalline condition, but the other crystalline marbles were deposited as ordinary limestones and have been changed subsequently to a crystalline condition by a process called metamorphism. The term metamorphism as now used refers to a marked change in the texture of the rocks, by which they are rendered harder and more crystalline. The metamorphic rocks include

*J. S. Newberry in the Report on Building Stones, International Exposition, 1876, Vol. III., p. 137; Sir Archibald Geikie, Text-Book of Geology, p. 119.

†Alabaster is the name of a compact variety of gypsum (sulphate of lime), but the word has also been applied to the "Oriental Alabaster" of Egypt, which is a true limestone. In the latter case alabaster is a marble; in the former it is not.

the gneisses, the schists, some of the marbles, the true slates, etc., all of which are believed to be produced by the metamorphism of siliceous, calcareous, and argillaceous sediments. According to the extent of its action metamorphism is spoken of as:

I. Local, or contact metamorphism.

II. General, or regional metamorphism.*

Contact or local metamorphism occurs in the vicinity of eruptive rocks, such as dykes or volcanic eruptions, where the effect has been to change sandstone to quartzite, and limestone and chalk to marble. Observations in many localities have shown that contact with eruptive rocks generally, but not always, produces metamorphism, and the distance to which the change may be traced varies from a few feet to two miles or more.† The reasons for this wide variation or total lack of metamorphism are not always evident.

Regional metamorphism‡ is the term applied when the cause cannot be traced to any evident source of heat. Such metamorphism is often found extending over large areas, thousands of square miles in extent and through thousands of feet of strata. The supposed agents of this work are heat, water, and alkali. The heat may be due to the heated interior of the earth or it may be induced by pressure—the pressure being either vertical from the superincumbent mass, or lateral from strains producing folding in the strata. The explanation of regional metamorphism is one of the most difficult and pro-

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*Irving, in his Metamorphism of Rocks, treats it under three heads, viz.: 1. Paramorphism, atomic or chemical changes. 2. Metatropy, molecular or physical. 3. Metataxis, mechanical.

Professor Alfred Harker in the Geological Magazine, Vol. VI., No. 1, January, 1889, p. 16, gives a fourfold division to the subject.

I. Low temperature and low pressure (hydro-metamorphism).

II. High temperature and low pressure (thermo-metamorphism).

III. Low temperature and high pressure (dynamo-metamorphism).

IV. High temperature and high pressure (plutono-metamorphism).

†Geikie, Text-Book of Geology, p. 566.

‡"Le nom de métamorphisme régional que j'ai proposé me parait plus juste que celui de métamorphisme normal, et moins vague que la dénomination de métamorphisme général."—Daubrée, Géologie Expérimentale, p. 138.

found problems of geology. Much light has been thrown on the subject by the experimental investigations of M. Daubrée, Sir James Hall and G. Rose. The following is a summary of the principal theories offered to explain regional metamorphism.

*The plutonic theory of metamorphism.**—According to the plutonic theory, the metamorphism is produced by the internal heat of the earth, which, through its long continued action, combined with the pressure of the overlying formations, causes a melting and recrystallization of the lowermost rocks. The water held in the original deposit plays an important role in this process, which in its superheated state, is an active agent in the solution and decomposition of the different minerals. Gases and vapors driven under pressure through the rocks from the heated interior of the earth are other important factors in the process. According to this theory regional metamorphism is similar to contact metamorphism, the heated interior of the earth acting in the one case like the dyke in the other. It therefore implies a greater metamorphism in the older or deeper seated rocks, a condition which is not wholly sustained by the facts.

The mechanical (tectonic) theory of metamorphism.—According to the mechanical theory of metamorphism, crystallization is due to the energetic thrust and pressure which the original strata have undergone in the process of mountain building. While it is true that the metamorphic rocks occur for the most part in mountainous regions, it is likewise true that the most violently folded rocks are not the most highly metamorphosed. In fact, it sometimes happens that highly metamorphosed strata exhibit a structure but little disturbed, while immediately adjoining highly folded strata show but little metamorphism.

The hydro-chemical theory of metamorphism.—According to the hydro-chemical theory of metamorphism as taught by Bischof and others, the saturation of the rocks with water through a long period of time, is sufficient cause for the metamorphism

*The following summary is based largely on Elemente der Geologie by Dr. H. Credner, Leipzig, 1887, p. 324 et seq.

of rocks on a large scale. The mineral substances are broken up and dissolved by the chemical action of the water, which then acts as a carrier to transfer the mineral matter to other strata. Thus, for example, the water, precipitated from the atmosphere, and holding carbonic acid and oxygen in solution, penetrates the rocks near the surface, where the oxygen is taken up in the process of oxidation and the carbonic acid is removed by the decomposition of certain silicates, or is used in dissolving limestone. The gases being used up, these reactions cease, and when the waters reach the deeper strata they are laden with mineral substances and serve as agents in changing or metamorphosing the rocks. The alkali and lime silicates carried down in this way combine with the magnesia and alumina silicates to form compound silicates (as feldspar, mica, etc.), which, owing to the exceeding slowness of the process, separate in a crystalline form. Likewise, the lime carbonate is slowly deposited in a crystalline state. By this process the mineral solutions from the upper strata are introduced into the deep-seated strata, effecting combinations and decompositions on the way, resulting in some instances in new minerals, in others in a change from the amorphous to the crystalline condition.

Bischof says: "In the conversion of sedimentary limestone into granular limestone the fossils are generally quite obliterated, but the bony parts of the radiata, etc., are found converted into calc-spar without any vestige of internal organic structure. This change appears to have been produced even in the most recent strata. These circumstances are indicative of the true nature of the metamorphism of limestone. The organic substance is gradually removed by water, while carbonate of lime is deposited in its place. If this displacement was complete, white granular limestone would be produced; when not complete, gray limestone would be produced. In this manner the origin of the gray streaks, veins and spots is quite intelligible."*

*Chemical and Physical Geology, by Gustav Bischof, Vol. III., p. 142.

The principal objection to this theory, as stated by Credner, is the enormous period of time required.

The crystalline rocks as original deposits.—Some geologists hold that the so-called metamorphic rocks are no more metamorphosed than any of the other rocks. In support of this theory it is urged that everywhere, where the group of the archaic formations is known, it is made up of the same members, possesses the same petrographical structure, and produces the same accessory constituents. Such a complete resemblance in 30,000 metres of strata, it is claimed, cannot be the product of an alteration and of the accidents of a process of crushing or of saturation with water. It is claimed further, that, had their structure resulted from a mechanical or hydrochemical metamorphism, there must have been a confused assemblage of rocks of different characters and not sharply defined stratification planes such as now exist.*

Prof. Favre says: "I have come to believe that there is little or no metamorphism for the great formations, and that all these formations were deposited very nearly in the state in which we see them."†

Dr. Hunt says:‡ "These crystalline rocks have doubtless, since their deposition, undergone molecular modifications (by what has been termed diagenesis) which have changed their original aspect; but something of the same sort is to a greater or less extent true of many sedimentary rocks to which we do not give the name metamorphic."

Conclusions.—The true explanation of metamorphism will doubtless be found in a combination of the foregoing processes, one being more active in one place, another in another place. The mechanical process has no doubt had much more to do with the crystallization of the limestones in the highly folded and contorted region of Vermont than in the slightly disturbed region of Arkansas. Some of the marbles were evidently not deposited in a crystalline condition, and that any of them ex-

*Elemente der Geologie, H. Credner, p. 327.

†Quoted from Chemical and Geological Essays, by T. S. Hunt, p. 347.

‡Chemical and Geological Essays.

cept the travertine marble were so deposited is highly improbable.

The crystallization of the Arkansas marbles.—The marbles of Arkansas occur in an elevated region where the strata are comparatively horizontal. The marble is mostly comprised in two beds: one, the St. Clair, at the top of the Lower Silurian; the other, the St. Joe, at or near the bottom of the Lower Carboniferous. Where the two occur in the same area they are separated by a thin bed of Eureka shale, or of Sylamore sandstone, or by both. The lower bed is underlain by a heavy bed of an amorphous, blue, Izard limestone, while the upper bed occurs at the base of a heavy bed of chert and cherty limestone. Both beds are fossiliferous, the upper one very much so in many places.

The fact that the marbles are fossiliferous and also that they are not accompanied by certain minerals which usually occur with the older metamorphic rocks, are sufficient reasons for some geologists to exclude them from the metamorphic rocks. The difference, however, is one of degree, and possibly of kind of metamorphism. It is evident that they were not deposited in their present crystalline state, for the fossil remains which are now completely crystalline were not so originally. Whether or not the change is due to metamorphism depends upon the limitations placed upon that word.

Of the four theories or explanations of metamorphism described above, the one that appears to best explain the crystallization of the Arkansas marbles is the hydro-chemical process. The objection to the plutonic theory is, that underneath the marbles are several beds of non-crystalline limestone, one purely calcareous, and several beds of dolomite. If the crystallization of the marbles were due to heat emanating from the interior of the earth, the underlying rocks, the limestones, sandstones, and shales, would also have been affected, which is not the case. The objection to the mechanical theory is the absence of any considerable folding of the strata. The objection to the original deposit theory is the presence of numerous fossils which certainly did not originally have their present

coarsely crystalline texture. While it is possible that the non-fossiliferous part might have been deposited in a crystalline condition, it is much more probable that the agency which produced the crystallization in the fossils produced it also in the remainder of the rock.

The numerous fossil casts in the overlying chert from which the limestone has been leached, show a possible source of some at least of the lime carbonate producing the crystallization. The limestone intercalated with the chert is also crystalline; in fact, it contains large quantities of marble. The local occurrence of semi-crystalline masses of limestone is better accounted for by the hydro-chemical theory than by any of the others. Both the St. Clair and the St. Joe marbles are in most places highly crystalline, but in places they contain a small percentage of amorphous material, and in a few places the amorphous part predominates, crystals singly and in large numbers being scattered through it.

The objection offered to the hydro-chemical theory by Credner is that it requires an enormous period of time.* This objection, however, can hardly be considered an adequate one. Another objection that might be offered to the hydro-chemical theory is, that the bed of amorphous Izard limestone which immediately underlies the St. Clair marble is not crystalline also. It must be remembered, however, that this objection is equally applicable to any theory that might be proposed, and possibly no other can account for it as well as this one. The marbles, as shown by their numerous fossils, were fragmental deposits and naturally pervious to water. The blue limestone underneath the marble is almost entirely non-fossiliferous, is very compact, and nearly impervious to water. This seems more evident from the numerous very fine veins of calcite, some of which are so fine as to be invisible to the naked eye. The occurrence of these veins, due no doubt to lime deposited from solution in fractures in the rock, shows that the crystallizing agencies have been at work in the Izard limestone,

*Elemente der Geologie, H. Credner, p. 326.

but that they have not been able to affect the body of the rock.

Conclusions.—In the light of the known facts, the explanation offered for the crystallization of the Arkansas marbles is, that it is caused by infiltrating waters charged with carbonic acid and lime carbonate in solution, which acting on the amorphous or partly crystalline limestone changed it by a process of solution and deposition into its present crystalline state. Further, that the local occurrence of amorphous or semi-crystalline masses is due to a difference in texture rather than in composition, the difference probably being that it is finer grained, more compact, and less pervious to water.

THE USES OF MARBLE.

Marble is subject to all the uses of other limestones described in Chapters V. and VI., and has, besides, distinctive uses of its own, mainly for ornamental and decorative purposes. Where it is used for other than decorative and ornamental purposes it is generally spoken of as limestone.

Architectural uses of marble.—The wealth, stability, and culture of a nation are generally reflected in its buildings, both public and private. As a nation advances in material prosperity we find the cheap and temporary wooden buildings replaced by more costly, durable, and elegant structures of stone, with their interiors decorated with marble. The greater the advancement in architecture the greater the quantity and variety of marble that will be required.

Marble has been extensively used for decorative purposes from very early times. We read of its use in the construction and decoration of Solomon's temple,* and it was also used for pillars and tiling in the palace of the Persian ruler Ahasuerus.† Ancient Greece and Rome made lavish use of marble in adorning the many beautiful palaces of those countries, the Romans using not only the marble of Italy, but imported marbles from all the world known at that time. It was used extensively in

*I. Chronicles, XXIX., 2; Josephus, Book VIII., Sec. 3.

†Esther, I., 6.

the time of Augustus, who is said to have found a town of brick and left a city of marble.

In modern times marble has been used extensively in all civilized nations. Probably the first marble quarried in the United States was in Montgomery county, Pennsylvania, and was used extensively for trimming and building in Philadelphia.* Marble is said to have been quarried at East Dorset, Vermont, in 1785, by Isaac Underhill, and was used for chimney backs, hearths, and lintels. Other quarries were soon opened and from 1785 to 1841 nine quarries were in operation. At Marbledale, Connecticut, a marble quarry was opened in 1800 by Philo Tomlinson, and others were soon opened at the same place.

Marble has not been as generally used for the construction of exterior walls of buildings as common limestones and sandstones, yet the large number of buildings in this country constructed wholly or in part of marble, shows that it is so used. Besides the public buildings, there are many private edifices constructed of marble. This is especially true in the immediate vicinity of good marble quarries. Thus, Washington, Baltimore, Philadelphia, and New York, situated near good marble quarries, contain proportionately more marble buildings than the cities in the Mississippi Valley, which are comparatively remote from marble quarries.

Because of its strength and beauty, marble is well adapted for trimmings, such as cornices, coping, lintels, water tables, etc., in stone and brick buildings. For such uses the light colored, durable marbles are the best, as bright colored marbles fade on long exposure, and white marbles stain easily and are too glaring in bright sunlight.

The most important use of marble in architecture is for interior decoration, in which it is almost without a rival. Granite, porphyry, alabaster, basalt, labradorite, serpentine, and malachite are sometimes used for such purposes, but no one of these is adapted to as many different uses as marble. It is used for columns, panels, tiles, staircases, fireplaces, mantels,

*G. P. Merrill, Stones for Building and Decoration, p. 6.

carved and moulded work of various kinds, such as cornices, capitals, friezes, architraves, vases, etc.

Its variety of uses admits of and requires, for the best effects, a variety of colors. The proper selection and arrangement of the different colors to give the best effect to the completed structure, however, calls for both architectural and artistic skill.

Mr. T. G. Jackson gives the following general rules for the use of marble: *

"1. Decorative carving in marble—as, for instance, in cornices, capitals, and friezes, where high relief and bold design are required—should be severe and conventional. Naturalism is forbidden by the stubbornness of the material except in the highest subjects, such as the human figure, which repays the expense of labor, or else in very low reliefs, where the labor of execution is reduced within moderate limits.

"2. Sculpture should be in white marble, or if in alabaster, only in such as is free from veins or stains of color.

"3. Moulded architectural features, such as vases, bands, strings, cornices, architraves and abaci, should be either in white or some uniform color, without markings or veins.

"4. Variegated marbles should be used only for panels or columns, or, in other words, on plain smooth surfaces, either flat or curved, so as to display the beauty of their markings to the utmost, without interfering with any of the structural lines of the architecture.

"5. Colored marbles should be used with moderation, too great a variety being avoided, and those of the quieter and more harmonious tones preferred for general use.

"6. Strong contrasts of color on a large scale are dangerous, and generally incline to vulgarity.

"7. Strong contrasts on a small scale, as in mosaics and inlaid work, are necessary.

"8. Stone and marble should be kept apart as much as possible."

For tiling there is probably no substance superior to marble

*Quoted from Marble and Marble Workers, A. Lee, p. 136.

in beauty and durability. It is used very extensively in the halls and corridors of hotels, in state and government buildings, where it is frequently laid in mosaic, thus adding to its beauty. All the variously colored marbles, including even fragments and small pieces, are used to advantage in work of this kind.

Marble steps and staircases are not only beautiful but exceedingly durable. Strongly marked and veined marbles are not suitable for this purpose, but dull, indistinctly clouded, or monochromatic colors are desirable. The white clouded marbles of Vermont and Georgia are largely used for this purpose, but are in no way superior to the grayish pink marbles of Arkansas and Tennessee.

"Mexican onyx" is sometimes used for mantels, but the supply is so small and the price is so high as to prevent any but a very limited use. The dark-colored marbles are generally preferred for mantels and fireplaces, the black marble being much in demand for that purpose. The dark-colored Tennessee marbles and the chocolate-colored and dark mottled varieties of Arkansas are well suited for such use.

For counters, sideboards, soda fountains, and cabinet work, as table, bureau, and washstand tops, all varieties of marble are used, depending on the supply in the market and the taste of the public. For such uses the Vermont, Italian, and Georgia white and white clouded marbles have been extensively used in this country, but of late years the colored marbles have been growing in favor, and their limited use in the past has no doubt been due in great measure to the insufficient supply in the market. The Georgia pink marble and many of the colored marbles of Vermont, Tennessee, and Arkansas are well adapted to this purpose, as they certainly present a more pleasing appearance than the plain white and are not so easily soiled or stained. The Arkansas marbles have in general softer, warmer colors than the others, which ought to be greatly in their favor. Excepting the so-called onyx marbles, which are the most beautiful marbles in the market, it is doubtful if any more hand-

some marble for cabinet work occurs in this country than the encrinital marble of Arkansas.

Uses of marble for monuments.—Marble has been and continues to be the principal stone used for monuments, although in late years granite has been growing in favor for that purpose. White and clouded marbles have been used much more extensively than the colored ones. The principal reason for this is that, being softer, they can be more easily and more cheaply quarried and wrought. But as red and gray granite are growing in favor for large monuments, there is no reason why colored marbles should not become fashionable for monuments both large and small, as soon as they are placed on the market in sufficient quantities and at corresponding prices. Many of the colored marbles are unsuitable for monuments on account of lack of durability, yet this objection does not apply to all.

Use of marble for statuary.—Mr. Ruskin says statuary marble is neither hard, brittle, flaky, nor splintery, but uniform and delicately—yet not ignobly—soft; soft enough to allow the sculptor to work it without force, and to trace on it the finest lines of finished form; yet hard enough not to betray the touch, or crumble beneath the chisel.* Furthermore the stone should have a pure white color free from flaws or imperfections of any kind. The localities where such stone can be obtained are very few and the supply of the best quality is never equal to the demand. While it is reported from many places in the United States, Vermont is the only locality from which any has been marketed, and only a limited amount of first-class statuary marble has been obtained there. The world's supply of this valuable stone is almost wholly obtained from the quarries of Greece and Italy. The ancient quarries of Grecian marble are situated on the island of Paros, and in Mounts Pentelicus and Hymettos; besides these are others on the islands of Scio, Samos, and Lesbos. These quarries have been abandoned for a great many years; recently, however, the Pen-

*Stones of Venice, III., 1.

telic quarries have been reopened. The Italian statuary marble comes from the Carrara region.

Marble production in the United States in 1880, 1887, and 1888.

States.	Value.		
	1880.	1887.	1888.
Vermont	$1,340,000	$2,275,000	$2,200,000
New York	224,500	60,000	50,000
Massachusetts	238,125	....	
Maryland	65,000	160,000	175,000
Tennessee	173,600	520,000	225,000
Georgia	....	150,000	125,000
California	....	5,000	5,000
Total	$2,041,225	$3,170,000	$2,810,000

The estimate for 1880 was compiled by Prof. G. P. Merrill from the Tenth Census returns, where the limestone and marble together are valued at $6,846,680. That for 1887 and 1888 is taken from the Mineral Resources of the United States for the corresponding years.

*Production of marble in 1889, by states.**

States and territories.	Number of individuals or firms operating quarries.	Number of quarries operated.	Product.		Total number employed.	Total wages, including salaries paid to office force.	Total expenses incurred in producing entire am't of marble.	Total capital invested.
			Cubic feet.	Total value.				
Total	74	103	3,320,213	$3,488,170	4,529	$1,809,211	$2,675,069	$15,092,842
California	4	4	33,792	$ 87.030	62	$ 43,615	$ 72,715	$ 554,000
Georgia	3	7	250,000	196,250	264	76,661	147,086	2,373,627
Maryland	3	3	333,305	139,816	206	78,240	112,504	576,904
New York	13	14	1,171,550	354,197	406	182,641	260,804	1,033,461
Tennessee	22	29	309,709	419,467	755	213,214	263,741	815,500
Vermont	22	36	1,068,305	2,169,560	2,716	1,163,973	1,739,988	9,346,928
Other states and territories	7	10	153,552	121,850	120	50,867	78,231	392,422

*Eleventh Census, volume on Mineral Statistics.

*Marble imported and entered for consumption in the United States, 1867 to 1883, inclusive.**

Fiscal years ending June 30—	Sawed, dressed, etc., not over two in. in thickness.	Sawed, dressed, etc., over two and not over six in. in thickness.	Veined, and all other in blocks, etc.	White statuary, brocatel, etc.	Not otherwise specified.	Total.
1867	....	....	$192,514	$2,540	$ 51,978	$247,032
1868	....	....	309,750	4,403	85,783	399,936
1869	....	....	359,881	3,898	101,309	465,088
1870	....	....	332,839	3,713	142,785	479,337
1871	$5,973	$ 317	400,158	1,134	118,016	525,598
1872	3,499	1,841	475,718	4,017	54,539	539,624
1873	3,124	....	396,671	4,148	69,991	473,955
1874	1,837	....	474,680	2,863	51,699	531,079
1875	1,456	523	527,628	1,623	72,389	603,619
1876	595	416	529,126	1,151	60,596	591,884
1877	2,124	....	349,590	1,404	77,293	430,411
1878	198	19	376,936	592	43,915	421,660
1879	184	....	329,155	427	54,857	384,623
1880	....	....	531,908	7,239	62,715	601,862
1881	339	....	470,047	1,468	82,046	553,900
1882	655	....	486,331	3,562	84,577	575,145
1883	619	....	533,096	2,011	71,905	607,631

During the calendar years ending December 31, from 1886 to 1889, and fiscal years ending June 30, for 1884 and 1885, the classification of marble was as follows:

Classification.	1884.	1885.	1886.	1887.	1888.	1889.
Total	$592,057	$527,881	$549,573	$529,933	$534,263	$701,518
Marble in blocks, rough, or squared, of all kinds	511,287	429,186	408,895	355,648	357,220	498,274
Veined marble, sawed, dressed, or otherwise, including marble slabs and marble paving tiles	12,941	43,923	96,625	142,405	107,957	115,909
All manufactures of marble not specially enumerated	67,829	54,772	44,053	31,880	69,086	87,335

Tariff.—The tariff act of 1890, as it relates to marbles imported into the United States, reads as follows:

Marbles of all kinds in block, rough or squared, sixty-five cents per cubic foot.

Veined marble, sawed, dressed, or otherwise, including marble slabs and marble paving tiles, one dollar and ten cents per cubic foot (but in measurement no slab shall be computed at less than one inch in thickness).

Manufactures of marble not specially provided for in this act, fifty per centum ad valorem.

*From the Eleventh Census Report, volume on Mineral Statistics, p. 620.

This differs from the law of 1883 only in the addition of the part in parenthesis, but this is of great importance to the manufacturers of marble in this country, as much of the ornamental marble came in thin slabs less than one inch in thickness.

CHAPTER XIII.

MARBLE IN THE UNITED STATES.

The varieties of marble are so numerous and so widely distributed that it is not possible to treat the subject in this place in anything like an exhaustive manner. From the data at hand an attempt is made to mention all marble deposits in the United States known to be of commercial value and briefly to describe the most important ones.

Marble is said to be found in twenty-one states and territories of the Union, and was quarried in 1889 in twelve of them, according to the report of the Eleventh Census.

Alabama.—In Alabama, marble of the following varieties is said to occur along the Cahawba River in Shelby county and on Big Sandy Creek: gray and red, red and yellow, fossiliferous buff, white crystalline clouded, with red and black. A white veined black variety is found on Six-Mile Creek between Prall's Ferry and Montevallo, and a compact red and white variety at Jonesborough and Village Springs.* A small sample of light brown fossiliferous marble with small grayish spots was shown the Survey, and reported to be found in a bed 75 feet thick in Lauderdale county about three miles from the Tennessee line and fourteen miles from Florence, Alabama.

Alaska.—In 1867 Prof. Davidson reported finding on Baranoff island, ten miles north of Sitka, a bed of pure white, finely crystallized marble free from marks and stains.†

Arkansas.—St. Clair marble, light grayish pink to brownish red; St. Joe marble light pink through various shades of red to chocolate brown, mottled with gray and green, crinoidal and saccharoidal; gray marble of the Boone chert formation; and onyx marble are all widely distributed throughout North

*Smithsonian Report, 1886, Part II., p. 374.

†Min. Res. U. S., 1883-84, p. 665.

Arkansas. Full descriptions and particulars of their distribution are given in other parts of this volume.

California.—In California, marble is said to be found in San Bernardino, Amador, Inyo, San Luis Obispo, El Dorado, Butte, Kern, Humboldt, San Diego, Solano, Placer, Nevada, Monterey, and Plumas counties,* in the first five of which it is quarried. By far the larger part of all the quarried product comes from Colton, San Bernardino county. It occurs in three varieties, one nearly pure white, one white clouded with gray, and one grayish black finely mottled with white. It contains about 6 per cent. of carbonate of magnesia, has a specific gravity of 2.75 and a crushing strength of over 17,000 pounds per square inch.† It is used for building, tiling, and dimension stone.

Inyo county produces several varieties of marble, one of which is a white, remarkably pure dolomite. A chemical analysis shows it to contain 54.25 per cent. of carbonate of lime, 44.45 per cent. of carbonate of magnesia, and but .60 per cent. of iron and silica.‡ It has a specific gravity of 2,80, which is equal to a weight of 175 pounds per cubic foot. Another handsome and unique variety has a white groundmass, interspersed with blotches, streaks, and branching, feathering, fern-like markings of a dark brown color, with occasional patches of yellow. Another variety is yellow of varying shades; another variety found in the near vicinity is a fine-grained black marble. The Inyo marbles are much cracked and seamed on the surface, but the quarry openings show that most of these seams disappear a short distance below the surface. These marbles are said to be the most promising in the West.||

In Amador county near Plymouth are coarse-grained, white and variegated marbles. The so-called onyx marble, a traver-

*Eighth Annual Report of State Mineralogist, 1888; Smithsonian Report, 1886, Part II.; Report on the Marble Quarrying Industry, Eleventh Census. A sample from Indian Diggings, El Dorado county, is pictured in colors in Plate LVIII., Vol. X., of the Tenth Census Report.

†Annual Report State Mineralogist of California, 1887, p. 213.

‡Tenth Annual Report State Mineralogist, 1890, p. 218.

||Merrill, Stones for Building and Decoration, p. 87.

tine formation, is quarried in San Luis Obispo county and Suisun City, Solano County,* and reported in other places. The first named locality is said to produce the finest quality, which is manufactured into mantels, clocks, vases, etc.; the mantels sell as high as $300 or $400 each.

Colorado.—Near Pitkin a handsome black marble is reported, also a chocolate-colored stone near Ft. Collins which resembles somewhat the Tennessee marbles;† a breccia marble is also reported near Boulder City.‡

On Yule Creek a marble belt 100 feet thick and five or six miles in length is said to occur.‖ The prevailing colors are pure white and white clouded with gray, and it is said to rival the Italian and Grecian marbles in color and texture.

A white dolomitic marble having a specific gravity of 2.86 is reported from Calumet, Chaffee county.§ This is probably the same marble referred to in the Eleventh Census report,¶ where it says a quarry has been opened fourteen miles north of Salida, in a dolomitic marble of a great variety of colors and adapted to monumental work, statuary, furniture, and building purposes.

Connecticut.—(See New England.)

Delaware.—Near Hockessin, New Castle county, there is a coarse white dolomite doubtfully classed as marble.

Georgia.—The quarrying of marble in Georgia is a comparatively new industry. No mention of it is made in the census report of 1880, and the report of 1890 gives a total product of 250,000 cubic feet, valued at $196,250 for the year 1889. It thus ranks fifth among the states in the amount and fourth in the value of marble produced. The product for 1888 was valued at $155,000.**

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*This is shown in colors in Plate LVII., Vol. X., of the Tenth Census Report.

†Merrill, Stones for Building and Decoration, p. 88.

‡Biennial Report State Geologist of Colorado, 1880, p. 33.

‖J. S. Newberry, School of Mines Quarterly, Vol. X., No. 1, 1888, p. 71.

§Building Stones of Colorado Rep., containing Anal. and Phys. Ex., made at the Col. State School of Mines, Denver, 1884, p. 7.

¶Volume on Mineral Statistics, p. 627.

**Mineral Resources of the United States, 1888, p. 541.

White and clouded marbles are said* to occur in Pickens, Cherokee, Gilmer, and Fannin counties; and colored marbles in Polk, Floyd, Whitfield, Catoosa, Chattooga, Gordon, Murray, Barton, and Walker counties; chocolate-red varieties, similar to those of Tennessee, are reported in Whitfield county; the outcrop in Red Clay Valley is said to be ten miles in length and varying from a quarter to a half a mile in width. However, almost the total output of the state is quarried by one company, the Georgia Marble Company, whose quarries are at and near Tate, Pickens county. This company produces a white marble, one nearly white, clouded with occasional dark spots (called "Kenesaw"), a white variety clouded with numerous nearly black spots (called "dark mottled creole"), a white and gray colored variety (called "medium cloud creole"), and a variety variously colored pink, salmon, rose, and green (called "Etowah"). All these varieties are highly and coarsely crystalline. They are used for cabinet work, interior decoration, building, and monumental purposes. Although these marbles have been on the market but a few years, they are constantly growing in favor, and supply a large part of the Western and Southwestern trade.

Idaho.—Marble is said to be quarried at Spring Basin, Cassia county, Idaho, in sufficient quantity to supply the local demand.

Illinois.—Variegated and black marbles are found in southern Illinois; a light-colored one is found near Thebes; oölitic marble occurs in Hardin county, and conglomerate marble is found in Pike county, Illinois.†

Iowa.—On Cedar River, near Charles City, is a beautiful coral marble, with fossils of all sizes up to eighteen inches in diameter. The prevailing color is light drab, but the fossils vary from yellowish to mahogany brown. The stone is commercially known as "Madrepore marble," and, according to Prof. G. P. Merrill,‡ it presents "an appearance totally unlike

*Merrill, Stones for Building and Decoration, p. 89.

†The Mining Magazine, New York, 1854, Vol. III., p. 227.

‡Stones for Building and Decoration, p. 91.

anything quarried elsewhere in America—an appearance at once grotesque and wonderfully beautiful."

The Iowa City or bird's-eye marble is another coral limestone that makes a pretty marble and would be valuable if it could be obtained in large pieces. The coral (*Acervularia davidsoni*) when polished shows the internal structure of the fossil, the ringed appearance of which bears a fancied resemblance to birds' eyes.

The "Iowa marble" quarried at Le Grand is used for ornamental purposes.* It is a light yellowish buff magnesian limestone of Lower Carboniferous age.

Maryland.—The census report shows that in 1889 Maryland ranked third among the states in the amount and fifth in the value of the marble produced.† The accompanying map‡ shows the marble area of the state. Dr. G. H. Williams, who has made a detailed study of the crystalline rocks of the state, says in a private communication to the Survey that the marbles in the eastern part of the region are included in gneiss, coarsely crystalline and snow-white, carrying well crystallized silicates, while further west they are much finer grained, compact, and either white or variegated with red, black, and gray veins, and without crystalline silicates. The first variety is called "Baltimore county," the second "Westminster" marble.

Nearly all the marble quarried comes from the vicinity of Cockeysville and is largely used for building in Baltimore, Washington, and Philadelphia. It was used in building the Washington Monument.

The following varieties were shown in the Maryland exhibit at the Centennial Exposition in Philadelphia in 1876: 1. Red marble. 2. Dark red veined with white. 3. Calico. 4. Mossy-veined. 5. Salmon-colored. 6. Lavender-veined. 7. Copper-veined. 8. Undulate, pink, and white. 9. Ruby. 10. Black.

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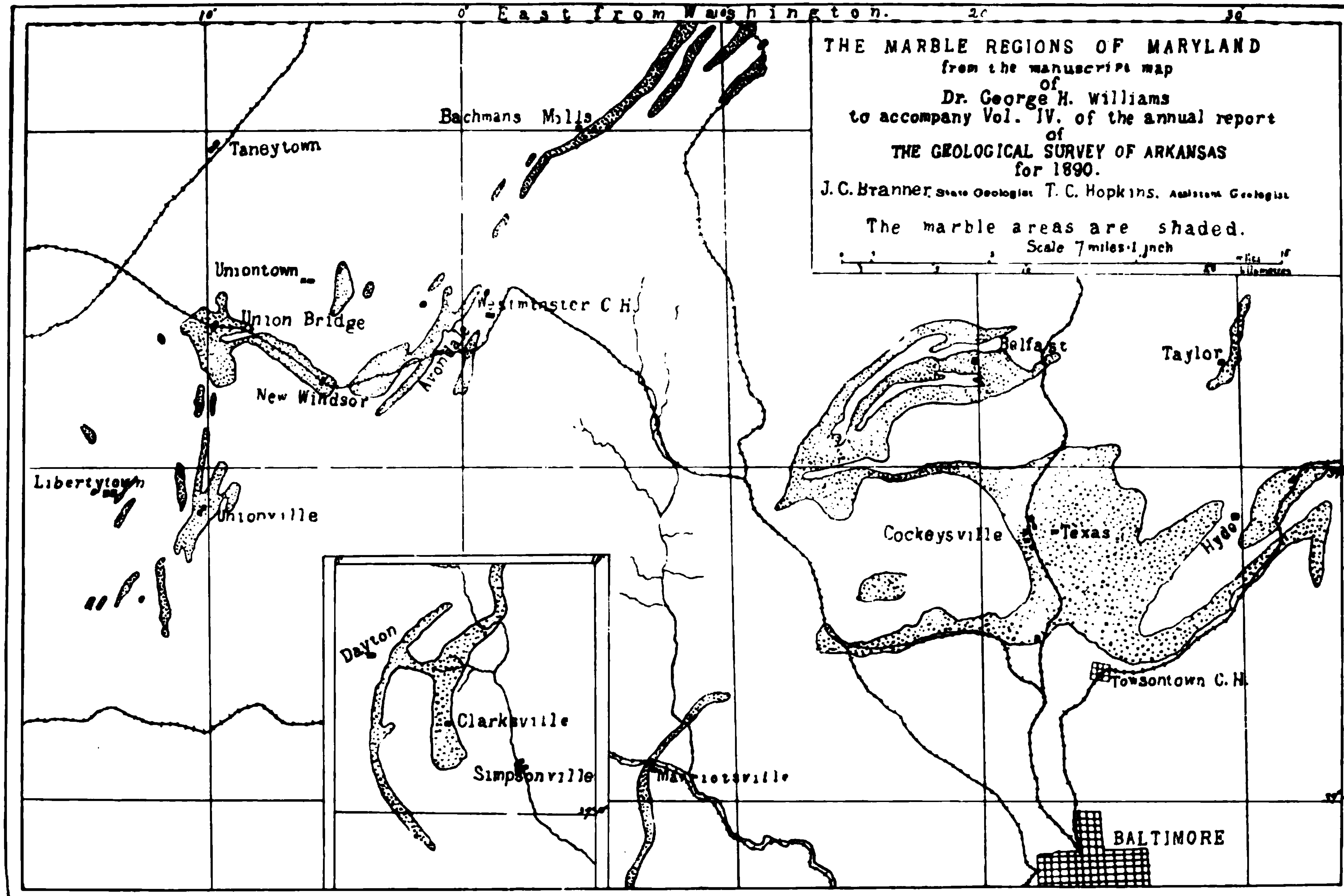
*Smithsonian Report, 1886, Part II., p. 378.

†These figures include the serpentine product.

‡The Survey is indebted to the kindness of Dr. George H. Williams of Johns Hopkins University for this map which was copied from a manuscript map prepared by him for Prof. Whitney The original is a detailed geological map on a scale of three and a half miles to the inch, and comprises a much larger area of the state.


East from Washington.
THE MARBLE REGIONS OF MARYLAND
from the manuscript map
of
Dr. George H. Williams
to accompany Vol. IV. of the annual report
of
THE GEOLOGICAL SURVEY OF ARKANSAS
for 1890.
J. C. Branner, State Geologist. T. C. Hopkins, Assistant Geologist.
The marble areas are shaded.
Scale 7 miles: 1 inch
Bachmans Mills
Taneytown
Uniontown
Union Bridge
New Windsor
Avondale
Westminster C. H.
Libertytown
Unionville
Dayton
Clarksville
Simpsonville
Marriottsville
Belfast
Taylor
Cockeysville
Texas
Hyde
Towsontown C. H.
BALTIMORE

The "Calico" or "Potomac" marble, found near the Point of Rocks, Maryland, is said by Prof. Merrill* to be the only true conglomerate or breccia marble that has ever been utilized to any extent in the United States. It consists of rounded and angular fragments of quartz and magnesian limestone of red, white, pale gray, and other colors, imbedded in a calcareous groundmass. It is a beautiful stone but polishes with difficulty owing to the difference in hardness between the quartz and the limestone.†

Massachusetts—(See New England).

Missouri,—"Beds of buff, gray, flesh-colored, red and variegated marble occur in the eastern part of Reynolds county; Big Creek, Marble Creek, and Stout's Creek, in Iron county; Marble Creek, Leatherwood and Cedar Creeks in Madison county. These beds often possess great beauty and would be desirable for table tops and mantels."‡

Limestone from the Boone chert formation is quarried in considerable quantities at Carthage, Missouri, where it is used for marble. A large mill for sawing the stone has been erected at the quarry. Marble is quarried also at St. Genevieve and Cape Girardeau.

Montana.—So far as known no marble of note is quarried in Montana, but a handsome specimen from that state is on exhibition at the National Museum. It has a dark blue-gray color with irregular wavy bands of dull chrome-yellow. (Merrill).

Nevada.—Marbles of different colors and textures are said to occur|| in the Tempiute Mountains in southeastern Nevada.

New England.—New England has always been the chief marble producing region of the United States, and at the present time nearly two thirds of the entire product of the whole country comes from one of the New England states,

*Smithsonian Report, 1886, Part II., p. 378.

†It is figured in Plate XLVI., Vol. X., of the Tenth Census Report.

‡G. C. Broadhead in the report of the Geological Survey of Missouri, 1874, p. 56.

||J. S. Newberry, School of Mines Quarterly, No. 1, Vol. X., 1888, p. 70.

Vermont. The accompanying map, which has been redrawn* from the map of the New England marble region compiled by Prof. Ezra Brainerd, and published in H. M. Seely's Marble Border, shows the marble area of western New England. It will be seen that the marble extends through western Vermont, Massachusetts, and Connecticut and into eastern New York. Although it has been extensively quarried in all these states, at the present time, with the exception of what comes from Lee, Massachusetts, the entire product comes from Vermont. We are told† that the marble industry of New England began at Marbledale, Connecticut, where in 1830 there were fully fifteen quarries and as many mills in operation. The industry subsequently flourished in East Canaan, Connecticut, Sheffield, Great Barrington, Stockbridge, West Stockbridge, and Lee, Massachusetts, all of which places were abandoned after the opening of the Vermont quarries except the last named, where the industry still flourishes.

The marble is now quarried in Vermont at Rutland, West Rutland, Proctor,‡ Dorset, East Dorset, Wallingford, Manchester, Pittsford, Brandon, Middlebury, North Ferrisburgh, and Swanton, the most extensive quarries being at West Rutland and Proctor.

The Vermont marble is a highly crystalline metamorphic limestone, white, clouded, or blue in color, and varying in quality in different places and in different layers at any one place. Prof. Hager‖ gives the following as a section of one of the West Rutland§ quarries, beginning at the top:

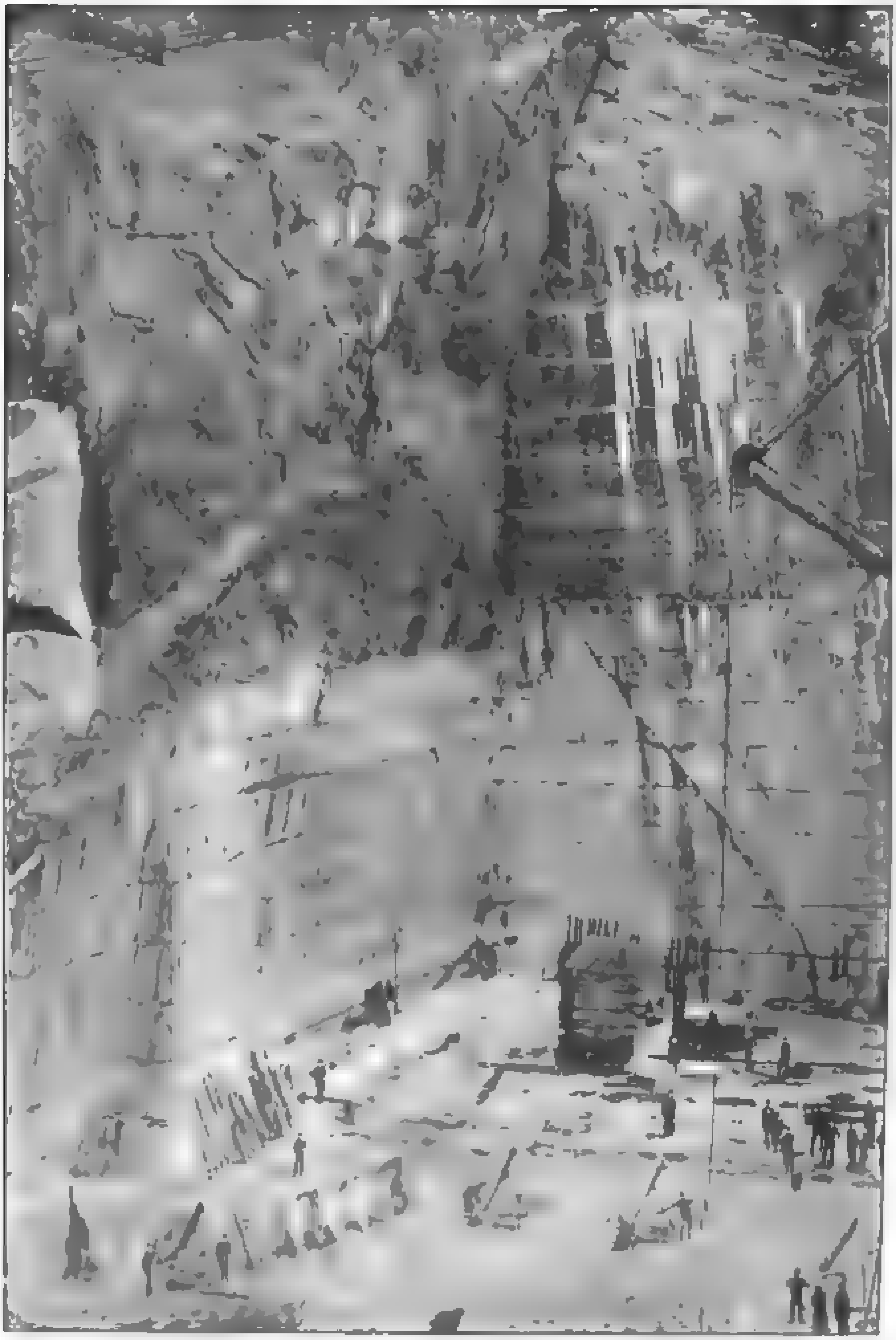
*With the consent of Prof. Brainerd.

†H. M. Seely, Marble Border, p. 29.

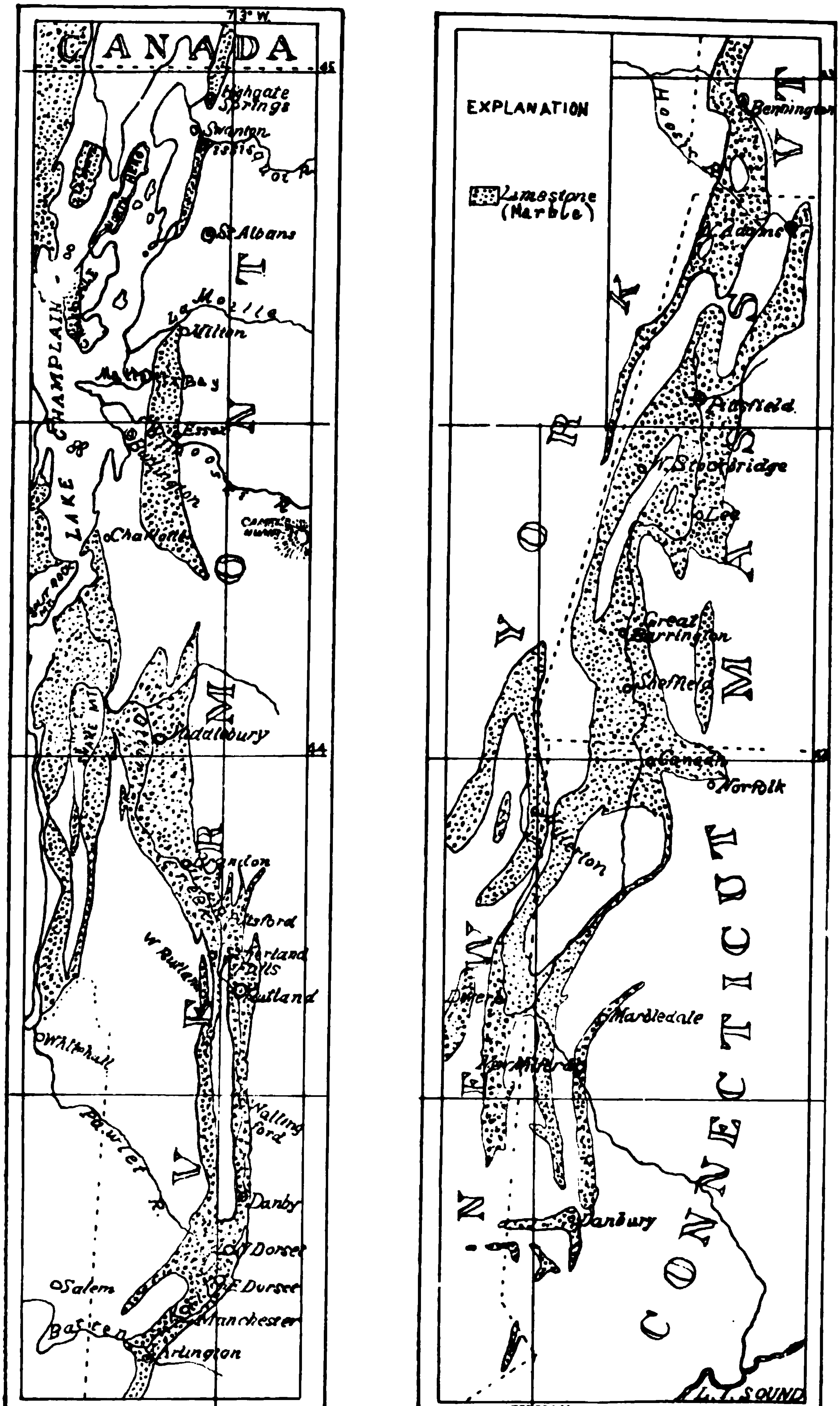
‡Formerly called Sutherland Falls.

‖Geology of Vermont, Vol. II., p. 764.

§In the Smithsonian Museum there are on exhibition a series of nineteen blocks of white and colored marbles from West Rutland, in sizes about 12 inches square and 2 inches thick; these are variously finished and represent the product of the Vermont Marble Company.



MARBLE QUARRY, PROCTOR, VERMONT.



THE MARBLE REGION OF NEW ENGLAND.

Section of one of the West Rutland marble quarries.

		Feet.
1.	Upper blue layer	4
2.	Upper white layer	3.5
3.	Gray limestone	5
4.	White statuary	3
5.	Striped	1.6
6.	New white layer	4
7.	Wedged white layer—8 inches to	2.5
8.	Muddy layer	4
9.	Striped green	4
10.	Camphor-gum	3
11.	White	9
12.	Blue	3.5

The total thickness of the beds at Rutland varies from 50 to 110 feet. They dip at an angle of 25° to 85°, with an average of 45°, and have been followed to a depth of 220 feet,* at which depth the layers become more nearly horizontal.

At Proctor (formerly known as Sutherland Falls) large quantities of marble are quarried and manufactured by the utilization of the excellent water-power at that place. The stone is very massive and the quarries are in the form of a hollow cube, from which blocks of almost any dimensions may be taken. Plate IX. shows a portion of the interior of one of the quarries at Proctor, said to be the largest marble quarry in the world. Two of the most valuable varieties of marble produced at this quarry are known as the dark and light mourning veins; the former being deep blue with dark zigzag lines and the latter nearly white with similar veins (Seely).†

At Dorset the quarries are mostly upon the sides of Mt. Eolus or Dorset Mountain, where more than twenty different layers of marble have been recognized, frcm some of which beautifully mottled and clouded varieties are quarried almost exclusively for monumental and decorative purposes.

The rarest and most valuable variety found in any of the quarries is the pure white statuary marble. The Vermont stone has been thought too soft for statuary, but it has been

*H. M. Seely, Marble Border, p. 39.

†A sample of this is shown in Tenth Census, Vol. X., Plate XXXIII.

used successfully for such purposes, the statue of Ethan Allen at the State House at Montpelier being a good example. The larger part of the product is used for headstones and footstones, and monuments of it may be seen in nearly every cemetery in the Union. It has an extensive use as an ornamental building stone and a limited use for plain masonry.

Besides the white and clouded marbles there are some colored marbles quarried in Vermont, the most noted of which are the Winooski, Plymouth, and Isle La Motte marbles.

The Winooski or Wakefield marble* occurs along the eastern shore of Lake Champlain, in the northwestern part of the state. It first appears one or two miles north of Burlington, and thence extends in a somewhat interrupted series north through St. Albans, and ends between that place and Swanton. The most extensive deposits occur in the high cliffs about Mallet's Bay, where it is so situated that the derrick which lifts the marble from the quarry may place it on the boat in Lake Champlain. The stone is an impure dolomite, and occurs in interbedded layers in the Potsdam sandstone, some of the layers being a more or less complete breccia. Red is the prevailing color, but many other colors occur. Several varieties may be found in the market, all of which receive a splendid polish, far more brilliant and durable than that of most of the white or clouded marbles, being much less easily scratched and stained. It is quarried at Swanton and made into tiling, and it has been quarried at Mallet's Bay, but it has never been extensively worked there owing to its hardness. Specimens of these colored marbles may be seen in the capitol buildings at Albany, New York, and Indianapolis, Indiana, in the Astor Library, New York City, and other public buildings.†

The Plymouth‡ marble is a fine-grained, compact, blue, or

*The Survey is indebted to Profs. G. H. Perkins and Ezra Brainerd for most of the information on the Winooski marbles.

†See Plates XXX., XXXI., XXXV., and XXXVI., in the Tenth Census Report, Vol. X., where several varieties of these marbles are figured.

‡Plymouth is abouth fifteen miles east-southeast from Rutland, outside the boundary of the accompanying map.

bluish brown stone, mottled with long stripes and figures of various shapes in white. The following analysis by Dr. Hunt shows it to be a dolomite:*

Analysis of Plymouth marble.

	Per cent.
Carbonate of lime	53.9
Carbonate of magnesia	44.7
Oxide of iron and alumina	1.3
Total	99.9

The Isle La Motte marble is a black marble, named from an island in Lake Champlain (see map,) where it is found. It also occurs on other islands in the lake and on the New York border. It has an extensive use for tiling, and a gray variety is much used for building stone. According to Prof. Hager† it was worked before the Revolutionary war, being thus the first marble quarried in the state.‡

New Jersey.—At one time a grayish marble was quarried extensively at Lower Harmony, Warren county, New Jersey. A beautiful stone known commercially as "rose crystal marble" has been quarried in the same county. It consists of large white, flesh-pink, and rose-colored crystals of calcite interspersed with black mica, green pyroxene, and black tourmaline. The quarries are not worked at present.||

*Smithsonian Report, 1886, Part II., p. 390.

†Geology of Vermont, Vol. II., p. 776.

‡For further information on the Vermont marbles, see:

1. Marble Border of Western New England. Published by Middlebury Historical Society, Papers and Proceedings, Vol. I., Part II.

2. The Winooski or Wakefield Marble, G. H. Perkins, American Naturalist, February, 1885.

3. The Marble Hills, The Century Magazine, October, 1890.

4. The Geology of Vermont, Vol. II.

5. Smithsonian Report, 1886, Part II., or Stones for Building and Decoration, by G. P. Merrill.

6. The Marble Quarries of Vermont, in the Mining Magazine, N. Y., Vol. II., p. 347.

7. The Marble Quarries of West Rutland, Vt., in the Mining Magazine, N. Y.,

8. Tenth and Eleventh Census Reports.

Vol. I., p. 91.

||Merrill, Stones for Building and Decoration, p. 96.

New York.—Marble has been quarried in New York at King's Bridge and Tremont, New York City; at Tuckahoe, Scarsdale, and Pleasantville in West Chester county near the Harlem railroad; at Hastings, Sparta, and Sing Sing on the Hudson River; at South Dover and Dover Plains in Duchess county; at Port Henry on Lake Champlain; at Gouverneur, Plattsburgh, and Thurman.* The marbles of the Highlands of the Hudson and in the Adirondack region are probably Laurentian, while that in Duchess and Putnam counties, which is continuous with the Vermont marble, is metamorphosed or altered Trenton limestone (Smock). The most extensive quarries are at Gouverneur, St. Lawrence county, where the "St. Lawrence marble" is quarried. The stone at the top is light gray, at the bottom dark blue (resembling when dressed some of the gray granites), both varieties being coarsely crystalline, very solid, and easily dressed. It is used extensively for monuments, but large quantities are used for building.

The Tuckahoe quarries furnish large quantities of a very durable coarsely crystalline marble which has been used in the United States Custom House at New Orleans, the United States Post-office in Washington, the United States Treasury building in New York, the City Hall in Brooklyn, and many other public buildings. The "Snowflake" marble quarried at Pleasantville is coarsely crystalline, some of the snow-white crystals, which give this marble its name, being an inch or more in length. It has been used in many public buildings, among others, St. Patrick's Cathedral. Prof. Newberry speaking of this marble says:† "After an examination of nearly all the quarries of marble in the United States, I do not hesitate to say that there is no other that can rival the 'Snowflake Quarry' in the magnitude of the deposit, in purity of composition and color, in strength and durability of the marble."

There are possibly several varieties at Sing Sing, as Merrill‡

*John C. Smock, New York State Museum of Natural History, Bulletin No. 3, March, 1888, p. 13.

†Snowflake Marble Quarry. Report of Prof. J. S. Newberry, N. Y., 1877, p. 4.

‡Stones for Building and Decoration, p. 97.

mentions a coarse white crystalline dolomitic marble; while Smock* describes a finely crystalline variety with a yellowish white shade. It has been used in the state prison building at Sing Sing and the Capitol at Albany, but is not much worked now.

The "Lepanto" and "French gray" colored marbles are quarried at Plattsburgh and Chazy in Clinton county, and are used extensively for mantels, table tops, and interior decorations.† A fine-grained, compact, dark blue-black, magnesian marble which, when polished, has a deep lustrous black color, is quarried at Glenn's Falls on the Hudson. Black marble is also quarried at Willsborough, Essex county.

At Lockport is a gray encrinital marble of the Niagara group, which has been used for decorative purposes.‡ Some of the fossils are tinged with red and others have a blue opalescent shade, giving the stone quite a handsome appearance.

At Warwick, Orange county, is found what Prof. Newberry‖ designates as "the most beautiful colored marble yet worked in the United States." Its prevailing color is carmine red, mottled with darker and lighter shades and veined with blue. But little of it has been quarried and the supply is said to be exhausted.

A verd-antique marble or ophiolite composed of dolomite and serpentine is quarried at Thurman, Warren county, and Moriah and Minerbah, Essex county.

The Onondaga limestone, a part of the Corniferous group, which extends across the state nearly east and west from the Helderberg Mountains to Lake Erie, is quarried in several places for a marble that takes a fine polish and is used for monumental, decorative, and structural purposes. Two of the

*Bulletin New York State Museum, No. 3, p. 40.

†The first of these is figured in Plate XXXII., Vol. X., of the Tenth Census Report, where it is wrongly set down as from Isle La Motte. (Merrill.)

‡J. S. Newberry, Report of Judges United States International Exposition, 1876. Vol. III., p. 158.

‖U. S. International Exposition, 1876, Vol. III., p. 157.

buildings of Syracuse University and the post-office at Syracuse are built of this marble.*

North Carolina.—Near Red Marble Gap in Macon county, North Carolina, is a marble having a bright flesh pink color, with patches and stripes of blue and yellow. It has a fine, even texture, and takes a beautiful polish. Other marbles of white or blue-gray color occur in Cherokee, Madison, and McDowell counties, but they are not quarried at present.

Pennsylvania.—Quarries of marble were opened in Pennsylvania about the time of the Revolutionary war, and during the early part of this century it was almost the only material used in the better class of stone buildings in Philadelphia. Since the development of the Massachuestts and Vermont marbles its use has not been so extensive.†

Marble has been quarried for many years in Montgomery county, Pa. According to Rogers, it occurs in the Lower Silurian rocks, which form the bed of a narrow valley about 58 miles in length from near Abington in Montgomery county to the source of Big Beaver Creek in Lancaster county. Heilprin remarks‡ that it is a curious fact that the limestones should be turned to marble on the south side of this valley, while on the north side they are impregnated with magnesia, forming dolomites.

The Montgomery county marble belt is about three quarters of a mile wide. Marble Hall is the most eastern point at which good marble is quarried, and the quarries are mostly located between this point and the Chester county line. At Spring Mill the stone is semi-crystalline, coarse to fine-grained, light blue in color and unevenly bedded. It is quarried and shipped to Philadelphia, Lancaster, Washington, and other cities for use in building and cemetery work. Near Bridgeport a semi-crystalline, light blue, evenly bedded marble is quarried. It has been used in the Girard College buildings, United States Custom House, Merchants' Exchange, and other

*Communicated to the Survey by Dr. W. C. Brownell, of Syracuse.

†G. P. Merrill, Smithsonian Report, 1886, Part II., p. 382.

‡Town Geology, p. 87.

buildings in Philadelphia. At King of Prussia and Henderson Stations marble is extensively quarried for use in Philadelphia and Baltimore.

Near Williamsport a black marble occurs which Prof. Newberry says* is a jet-black stone that takes a brilliant polish but is not quite equal to the Belgian stone in purity. It contains a few specks of pyrites with an occasional fine line of white marking the section of a fossil.

Tennessee.—The fact that the Tennessee marbles are quarried more extensively than any other colored marbles in the United States, combined with the close lithologic, geologic, and geographic relations which they bear to the marbles of Arkansas, make them of special interest in this connection.

According to Prof. Safford, State Geologist, the marble at one time formed continuous beds entirely across East Tennessee in a northeast-southwest direction; but deep erosion has cut the beds into separate areas. The Tennessee marbles occur in the rocks of Lower Silurian age in the Trenton or Nashville group.

Section across the Trenton or Nashville group, near Knoxville, Tennessee, in descending order.†

		Feet.
7.	Calcareous shale, about	400
6.	Red marble, fossiliferous, mostly red with gray and green layers, about	300
5.	Calcareous shale, with flaggy limestone, about	500
4.	Iron limestone	250
3.	Calcareous shale, with intercalated iron limestone and flaggy limestone	400
2.	Red and gray marble, coralline, grayish white and variegated	380
1.	Blue limestone, argillaceous, fossiliferous	500

These beds vary greatly in texture, composition, and thickness throughout the state. In many localities there is no marble of commercial importance, but where the marble is quarried it is obtained from numbers 2 and 6 in the above section.

Marble occurs in Tennessee in Hawkins, Knox, Loudon, Blount, Grainger, Jefferson, Roane, Monroe, McMinn, Bradley, Meigs, Anderson, Union, and Campbell counties, in the first

*Report of Judges, International Exposition, 1876, p. 158.

†Geology of Tennessee, by J. M. Safford, 1869, p. 230.

two of which it has been quarried extensively, and in the next two, Loudon and Blount, quarries have been opened within the last few years

Dr. J. M. Safford says* that this industry began in 1838 at Rogersville, Hawkins county, where the Rogersville Marble Company operated for several years. In 1844 this company sold out, and soon after the new proprietor sent two blocks of this stone to the Washington Monument. These blocks so attracted the attention of the building committee for the extension of the Capitol that it was decided to use this marble for interior decoration, and the Government quarry was then opened about nine miles southwest of Rogersville. This public notice soon opened up an extensive market and many other quarries began operations. While the Hawkins county marbles continue to be the handsomest and highest priced marbles quarried in the state, the product of the Hawkins county quarries is growing less each year, a fact which is probably due to the lack of transportation facilities as compared with those of Knox county. The Hawkins county marble more nearly resembles the St. Joe marble found on Well's Creek, Arkansas, than any other found in this state.

In Knox county† the principal quarries in operation in 1890 were those at Caswell, Concord, and at the confluence of the French Broad and Holston Rivers.

Caswell Station is on the East Tennessee, Virginia and Georgia Railway, six miles northeast of Knoxville, and the quarries are about half a mile from the road, with which they are connected by a tramway. The marble varies in color from light pinkish gray to a dark chocolate-brown. It occurs in isolated masses of varying sizes, some of them large enough for the use of the channeling machine. This broken condition of the rock is due to the folding of the beds. The cavernous openings between the masses are mostly filled with a dark red clay. Some of the masses of rock are comparatively

*Geology of Tennessee, 1869, p. 508.

†The remarks on the Knox county marbles are mainly based on personal observation, made in the summer of 1890.

sound but many of them are intercalated by seams, cracks, and flaws, necessitating the handling of a large quantity of waste material.

The marble at Concord closely resembles that at Caswell, but the lighter colors are more abundant at Concord. The specific gravity of a sample from the bottom of the Concord quarry is 2.72, and of one from the top 2.71. There was formerly a mill in operation at Concord, but the product of the quarries is now shipped to the mills at Knoxville, where it is prepared for the market.

The marble at the confluence of the French Broad and Holston Rivers, four miles from Knoxville, is essentially different from that at Concord or Caswell. It has a light gray color with a faint pinkish tinge. It is exposed in larger quantities than at the other places, the masses are not so cavernous, and the texture is more uniform. It has been used more extensively for building than for purely ornamental purposes. Its homogeneity and pleasing color make it a valuable and desirable building stone. The post-office and Custom House at Knoxville, and the new Custom House at Chattanooga are built of it. In these buildings the natural beauty and color of the stone are concealed by the manner of dressing. The quarrying is mostly done by hand, and the blocks moved by trucks from the quarry into the mill where they are sawed into the desired shape. From the mill the marble is passed down an inclined plane to boats on the river which is close to the quarry.

The Crescent quarry, about two miles from Knoxville, is in a marble somewhat resembling that just described. There is a mill at the quarry and channeling machines are used in quarrying the stone. The quarry was not in operation in 1890. Numerous smaller quarries in the vicinity of Knoxville are occasionally worked, the product being hauled to the mills at Knoxville.

Some very beautiful variegated marbles were on exhibition in Knoxville in the summer of 1890, that were said to have

come from Blount county, about fifteen miles southeast of Knoxville, where quarries were being opened.

The census report of 1880 gives the total value of the Tennessee marbles quarried during the preceding year at $173,600. The value of the product for 1888, according to the Mineral Resources of the United States, was $225,000, of which $100,000 came from Hawkins county and $125,000 from Knox county. For 1889 the product, according to the census report, was 309,709 cubic feet, valued at $419,467, ranking fourth among the states in the amount produced and second in the value of the product. The product for 1889 was mainly from Knox, Loudon, and Hawkins counties, with small quantities from Hamblen, Blount, and Jefferson counties.

The Tennessee marbles are mostly used for interior decoration and cabinet work, and may be seen in public and private buildings in nearly every city in the Union.*

Texas.—The State Geologist of Texas says there are at least three possible sources of marble in the central mineral region of that state, but there is not enough known of them at present to report on their value.†

Utah.—Prof. Newberry‡ mentions heavy beds of white marble three miles from the town of Frisco in Utah; also a

*But little accurate information is available on the Tennessee marbles. Brief notices of them may be found in:

1. Tenth Census Report, Vol. X.

2. Eleventh Census Report on Mineral Industries.

3. Geology of Tennessee, 1869, by J. M. Safford.

4. Resources of Tennessee, 1874, by J. B. Killebrew and J. M. Safford.

5. Smithsonian Report for 1886, Part II.; or Stones for Building and Decoration, by G. P. Merrill, N. Y., 1891.

6. Report of Judges U. S. International Exposition, 1876, Vol. III., p. 157.

7. Resources of Tennessee, by G. B. Cowlan in The Age of Steel, St. Louis, 1891.

8. The Marble Region of Knoxville, Tennessee, by G. P. Merrill, in Stone, Indianapolis, November, 1892.

9. A Sketch of the Geology of Tennessee, by R. O. Currey, in The Mining Magazine, Vol. IX., p. 34, N. Y., 1857.

†First An. Rep. Geol. Survey of Texas, p. 369.

‡School of Mines Quarterly, Vol. X., No. 1, p. 71.

white marble in the Wasatch Mountains east of Salt Lake City.

Vermont.—(See New England.)

Virginia.—Prof. Rogers* describes the following varieties as occurring in the Valley of Virginia:

1. A dun colored marble, very homogeneous, close-textured and susceptible of a fine polish.

2. A mottled bluish variety, which is rather less fine-grained than the former but quite ornamental in its appearance.

3. A fine-grained massive gray marble.

4. A white marble which in susceptibility of polish, fineness and evenness of grain, and purity of color can scarcely be excelled.

5. A shaded marble found only in Rockingham county.

The census report for 1890 says that a marble quarry has been opened and worked at Mountsville, Loudon county, where white, creamy white, green, and green and white mixed marbles are obtained.

Washington.—The reports of the State Geologist of Washington mentions several different kinds of handsome marbles found in Skagit, Cowlitz, Okanogan, and Stevens counties in that state. He gives the results of various tests on different varieties, and pronounces them eminently suitable for structural and ornamental purposes. While no marble has been quarried, he states that necessary machinery for quarrying has been placed in Stevens county.†

West Virginia.—Dark variegated, gray, and black marbles are reported in West Virginia.‡

Wyoming.—Marble is reported in several places in Wyoming, but so far as known none has been quarried. In Muskrat Canyon are two varieties: a pink marble of uniform color, and a mottled marble having a dark blue color, with narrow

*Geology of the Virginias, New York, 1884, p. 212.

†Second An. Rep. of the State Geologist of Washington, 1892, p. 55.

‡Resources of West Virginia, by M. F. Maury and William M. Fontaine, Wheeling, 1876, p. 314.

veinlets of white, pink, and red running through it. Both varieties are said to take a fine polish, and to be obtainable in large blocks.*

White and variegated marbles are said to occur in the Platte River valley on both the extreme east and extreme west, the best quality being on Cedar Creek, in the eastern part of the valley.†

*Annual Report of the Territorial Geologist, January, 1888, p. 68.

†Stone, Indianapolis, Vol. I., No. 12, April, 1889, p. 293.

CHAPTER XIV.

MARBLE IN COUNTRIES OTHER THAN THE UNITED STATES.

If it is difficult to mention, however briefly, all the localities at which marble occurs in the United States, it is still more difficult to mention those at which it occurs in other countries. The list here given must therefore be regarded as necessarily incomplete.

*Canada.**—At Mount Mark, Vancouver Island, B. C., there are thick beds of white, dove-gray, and bluish tinted marble, interstratified with diorite; a variegated marble is found on the same island in Beaver Cove quarry. A gray crystalline marble largely used for monumental purposes is quarried at Horton, Ont. In the counties of Lanark and Renfrew, Ont., there is a bed of Laurentian limestone several thousand feet thick, which at various points contains banded marbles; so far it has not been quarried except for making lime. Considerable quantities of a coarse-textured, dark-banded Laurentian marble has been quarried near Arnprior, Ont., for use in the decoration of the Houses of Parliament at Ottawa. In the township of Greenville, Quebec, is a marble in which serpentine usually runs in green or yellow bands marking the foliation of the rock. In some places the serpentine is absent, in which case the marble is coarse-grained and white. Serpentine marble is also found at Hull, Quebec. At St. Joseph, Beauce, Quebec, is a white-veined red marble in a bed from ten to forty feet thick. About a mile and a half southeast of Philipsburg, Quebec, a black marble was quarried years ago, but this was abandoned soon after the opening of the quarry at Glen's Falls, N. Y.

Mexico.—The travertine or stalagmitic deposit, popularly

*The notes on the marbles of Canada are mainly compiled from the Descriptive Catalogue of the Economic Minerals of Canada in the Colonial and Indian Exhibition, London, 1886, and from the reports of the Canadian Geological Survey.

known as Mexican onyx, is one of the most beautiful and costly marbles known in the market. It is composed of aragonite, and is harder than the calcite marbles—so hard indeed that it takes a polish as brilliant as the true onyx for which it is named. It is of a fine even grain, has a close surface and varied colors, being green, red, amber, purple, yellow, brown, and white, beautifully banded, veined, and mottled. It is translucent, and the colorless varieties in thin slices are transparent. It is stated by Signor Aguilera that slabs two feet in diameter and a quarter of an inch in thickness have been used as window panes in the building of the University of Mexico.* The cost of transportation is so great that it has not been extensively used. It is employed for table tops, mantels, clocks, pedestals, counters, etc., and has always commanded very high prices.† The composition of the lighter variety of this stone, according to M. Barcena, is as follows :‡

Analysis of Mexican onyx.

	Per cent.
Lime	55.00
Magnesia	1.25
Water, iron, and manganese	0.10
Carbonic acid	42.40
Sulphuric acid	1.25

Specific gravity 2.91, equivalent to a weight of 181 pounds per cubic feet.

It is found in several localities in Mexico, the most extensive quarries being in the State of Puebla, near Tecalli.

Another variety of this marble is one in which the original deposit has been broken up and the fragments re-cemented with a translucent substance, giving it the appearance of a brecciated marble.||

At Hermosille there is said to be a white saccharoidal mar-

*Smithsonian Report, 1886, Part II., p. 482.

†In the New York market, slabs one inch thick are valued at $2.50 to $6.00 per square foot, equivalent to $25.00 to $60.00 per cubic foot—Merrill, Stones for Building and Decoration, p. 120.

‡Smithsonian Report, 1886, Part II., p. 483.

||Stone, January, 1890, p. 151.

ble.* White crystalline marbles are found in the State of Sonora, State of Mexico and at Vera Cruz; a compact yellowish variety occurs at Vera Cruz; a dull pinkish variety and a fossiliferous water-blue and gray variety in the State of Puebla.†

West Indies.—The rocks of Bermuda consist essentially of limestones popularly known as coral limestone, the harder varieties of which are in some places worked as marble. In Cuba, a Madrepore marble and a cavernous white brecciated marble are reported. In Jamaica marbles are said to be "abundant along the southern base of the central chain of the eastern mountains and a great variety occurs in other localities, including black, white, green striped with gray, and white with brown and red."‡

South America.—Pink marble occurs at Corillas on the shores of Lake Titicaca; it was formerly used in buildings at La Paz, Peru.||

Marble has been found at many places in Brazil, but the lack of transportation and the small demand for it has thus far prevented any development of the known localities. Several varieties are said to occur in the State of Ceará, namely at Serrote de Cantagallo, at Giboia about 25 miles from Fortaleza; also in the Soure district in the Morro de Jericoaquara, in Aracaty, and in Cariri.§ In the State of Sergipe Cretaceous marble is exposed on the Rio Sergipe at Toque between Porto da Rede and Pintos.¶ In the State of Rio de Janeiro white and gray marbles occur in the gneisses and schists near Barra do Pirahy. Beautifully mottled varieties were found in 1884 on the prolongation of the Dom Pedro Segundo Railway in the municipality of Santa Barbara, State of Minas Geraes.** A black

*Burnham's Limestones and Marbles, p. 113.

†Smithsonian Report, Part II., 1886, p. 611.

‡Burnham's Limestones and Marbles, p. 110.

||Expédition dans les parties centrales de l'Amérique du Sud, par Francis de Castelnau, Vol. IV., p. 388.

§Ensaio Estatistico da Provincia do Ceará por Thomaz Pompeo de Souza, Brazil, p. 145.

¶Transactions Amer. Philosophical Soc., Vol. XVI., 1889, p. 388.

**Revista de Engenharia, Rio de Janeiro, Sept. 14, 1884, p. 199.

variety occurs in the municipality of São Roque, green varieties near Sorocaba and south of Faxina, and white near Sorocaba and Morro da Boa-Vista in the State of São Paulo.*

The State of Parana seems to be rich in marbles; a green variety is found fifteen miles north of Curitiba.† Green, black, and variegated occur at Encruzilhada in the State of Rio Grande do Sul.

‡*England.*—England is well supplied with colored marbles. The Devonshire marbles, several varieties of which are quarried in different places, are used extensively for chimney-pieces, columns, and inlaid slabs. At Ipplepen, and in the vicinity of Totness, there is a handsome reddish variety; at Kitley Park occur green marble and rose-colored dolomite, both of which are used for ornamental purposes; in North Devon there are varieties of black and white at Bridestow, South Tawton, and Drewsteigton. The Purbeck and Sussex marbles were formerly used for decoration in ecclesiastical buildings, but have now fallen into disuse. In Derbyshire there are several varieties of marble in the Carboniferous limestone; in color they are black, blue, and light gray to russet. Black marble is quarried near Ashford. The Mona marble, an ophiocalcite, is obtained in Anglesea. Its colors are dark green, light green, and sometimes purplish, irregularly blended with white.‖ The following varieties are mentioned by Gwilt as occurring in the Isle of Man: black, gray, shelly, and encrinital marble from Poolwash; extremely hard, durable, black marble from Port St. Mary; pale marble from Scarlett. Castle Rushen, 900 years old, is built of the Scarlett stone.

Ireland.—The black marbles of Ireland have a world-wide reputation. The principal quarries are at Kilkenny and Galway, and the most extensive mills for cutting and polishing are in Dublin. The Kilkenny marble when first cut is quite black,

*Relatorio da Commissão geographico e geologica de São Paulo, 1889, pp. 24, 40.

†Proc. American Philosophical Soc., 1879, p. 252.

‡The notes on English marbles are taken principally from E. Hull's Building and Ornamental Stones.

‖Gwilt, Encyc. Arch., p. 492.

but the organic matter gradually passes off and the white marks of fossils appear on the surface. The Galway marbles are at Angliham and Menlough, from which large quantities are exported. Black marble is also found at Churchtown and Doneraile, County Cork, Carlow, Tralee, and in the Islands of Kenmare River. Gray, red, and variegated marbles, some of which are encrinital, are obtained at several localities.

Scotland.—At Tiree, in the Hebrides, off the coast of Scotland, associated with the Laurentian gneiss is a pink marble with disseminated crystals of dark green augite (?), which give it a porphyritic appearance. The Iona marble is gray and white, sometimes mixed with yellowish spots or veins of steatite called Icolmkill pebbles; the Skye marble is veined and gray; the Assynt varieties are gray, blue, and dove-colored; Glen Tilt marble is white and gray with occasional yellow and green spots; marble of Balliculish is gray and white, as are those of the Boyne; Blairgowrie marbles are white and suitable, it is said, for statuary purposes.*

France.—A great many varieties of marble are quarried in France, only the most noted of which are mentioned here. Sarrancolin is one of the best known and most admired of foreign marbles.† Its colors are green, red, white, brown, and orange, veined or mottled in sub-angular patches. It is a type of mottled and brecciated marbles much esteemed for mantels and other interior decorations. It comes from the Pyrenees and is exported from Marseilles. It is quarried in the hills near Ilhet and Berede. The quarries were first worked in the time of Louis XIV. In 1862 they were reopened and are now in active operation. They supplied the marble for the thirty great monolith columns of the grand staircase at the Paris Opera House. The Campan is a beautiful and well known variety of marble, also from the Pyrenees; its prevailing color is a pale yellowish green, mottled with white in figure-like "mackerel clouds." A dark green variety containing much

*Gwilt, Encyc. Arch., p. 494.

†J. S. Newberry, Report of the Judges U. S. International Exposition, 1876, p. 146.

red is called the "Campan Rouge" (Newberry). It sells in France for $4.50 per cubic foot (700 francs a cubic meter, Violet). Brocatelle is a beautiful marble which, according to Violet,* is found in the Jura Mountains and is much used for interior work. It is fine-grained and compact, of a light yellow color with irregular veins and blotches of a dull red, with patches or nodules of white crystalline calcite. Violet divides them into three classes: the yellow brocatelle, the variegated, and the yellow variegated (*La brocatelle jaune, la brocatelle fleuri, et le jaune fleuri du Jura.*)

The griotte or French red marble (named from the griotte cherry) is one of the most brilliant marbles found anywhere. When this bright red is spotted with white calcite it is called "bird's-eye griotte."† Another bright red marble, known as Languedoc marble, is found in various places in the Pyrenees, notably at Montagne Noire. *La petit antique*, and *le grand antique* are two very handsome black and white marbles. The Caen stone, which is sometimes used as marble, has been mentioned under limestone. A white marble used for statuary purposes is quarried near St. Beat on the Garonne.

Germany.—A great many beautiful marbles are quarried in different parts of Germany, only two of which are said to be imported into the United States to any extent;‡ they are said to come from Nassau. The Formosa is dark gray and white mottled, blotched with red. The Bougard is lighter and the tints more obscure (Merrill).

Italy.—The Italian marbles are more widely exported and better known throughout the world than any others. There is possibly not a state or city of any size in the United States in which it has not been used. Such large quantities are quarried and exported from the vicinity of Carrara that Carrara‖

*Les Marbres, etc. Rapports sur L'Exposition Universelle de 1878, XXVII., p. 33.

†Violet, Les Marbres, p. 15.

‡Stones for Building and Decoration, p. 160.

‖This is a general name given to all the marbles quarried in the Alps near Carrara, Serravezza, and Massa, and includes several varieties. The word Carrara is said to be derived from the Latin *quarraria*, from which the English word quarry is possibly derived.

marble and Italian marble are sometimes used synonymously. The white statuary marble of Carrara is one of the most valuable marbles in the market; indeed, for statuary purposes it has no equal, unless it be the Parian and Pentelic marbles of Greece. It is a pure white, fine-grained, saccharoidal stone, without spots or flaws, and on a polished surface has a peculiar soft, waxy lustre.

The ordinary white or clouded marble is the kind that is so extensively imported into this country and used for monuments. White is the prevailing color, but it is sometimes clouded with blue gray or black. The coloring matter is sometimes diffused through the rock in minute quantities, giving it a faint bluish tinge. The Carrara quarries are supposed to have been opened about 100 B. C. The output for 1882 was about 150,000 tons (Welch), of which about 25,000 tons were used in the United States, 25,000 in France, and 18,000 in Great Britain. A writer in the Century Magazine* says that there were upward of 400 quarries in operation in 1882, employing 5000 men. Further, he says, in order to produce the 150,000 tons, probably 500,000 tons are quarried, the difference being due to the waste in quarrying, which is mostly done by blasting. In addition to the injurious effects of the blast, the marble, which is quarried from 500 to 1500 feet up the steep mountain side, is sometimes blown from the bed and rolls down the steep slope. The evil effects of this process are seen in pieces of the marble which have been exposed to the weather for a few years by the opening of hidden seams and cracks. No improved machinery is used in these quarries; it is supposed that the nature of the surface prevents it.

Although not exactly uniform in composition, the following

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*Robert W. Welch, Century Magazine, June, 1882, p. 240.

A. Lee, in Marble and Marble Workers, p. 11, gives 550 quarries in the Carrara district, of which 70 are at Massa, 100 at Serravezza, Stazzema, and Pietra Santa, and the remainder in the near vicinity of Carrara, giving employment to 8,460 men, of which 5,030 are in the quarries. He gives the annual output as 170,000 tons.

W. P. Jervis, in the Mineral Resources of Italy, 1862, gives a list of 71 of the most noted quarries and the quality of marble obtained from each one.

analyses show the Carrara marble to be a remarkably pure carbonate of lime.

*Analyses of Carrara marble.**

	I.	II.	III.	IV.
Carbonate of lime	99.24	99.26	98.10	98.77
Carbonate of magnesia	.28	.28	.90	.90
Carbonate of manganese	.....	.....	1.00	.....
Iron oxide	.29	.25	.....	.....
Iron oxide and alumina	.....	.....	.....	.08
Silica	.....	.....	.....	.16
Total	99.81	99.79	100.00	99.91

Much of the Italian marble is shipped to other countries as ballast, hence the freight rates in general are low.

Besides the white and clouded marbles from the Carrara district, numerous other valuable varieties are shipped from Italy, one of the most popular being Sienna marble, which has a bright yellow color and a fine-grained and compact texture.

The Portor, or black and gold marble, is another beautiful variety. It is a black siliceous marble with yellow veins which are sometimes reddish or brown. It is quarried mostly at Porto Venere and the Isle of Palma, but small quantities are found at Carrara, Serravezza, and Monte d'Arma.

The travertine found in large quantities near Rome and in other parts of Italy, has been largely used for both building and ornamental uses. It seems to have been a favorite with the ancients.

The Ruin marble is a very compact, yellowish or drab colored rock, which appears to have been fractured in every conceivable direction by some agency, and the openings between the fragments filled with a calcareous or ferruginous cement. When cut and polished the slabs contain configurations resembling the ruins of old castles, hence its name. It occurs near Florence and at the bridge of Rignand, Valley of the Seine.†

*No. I., Wittstein, Building and Ornamental Stones, p. 130.
No. II., Bischof, Geology, Vol. III., p. 141.
No. III., Prestwich, Geology, Vol. I., p. 34.
No. IV., Kaeppel, Jahresber. Chemie., 1882, 962.

†Smithsonian Report, 1886, Part II., p. 481.

The yellow marbles of Verona and Graynana are entirely different from those of Sienna, having a brownish hue, and taking a dull polish. Other varieties are black marble from the Colonnata quarries; breccia from Graynana and Serravezza; red from Castel Poggio; *rosso di Levanto*, a deep purplish red with lighter veins; Verona red, a light red, with fawn colored patches; *verde di Levanto*, dark green interlaced with purple and red veins; *verde antique*, deep green with white veins; Genoa green, dark green, with dark patches and white and gray veins, etc.*

Greece.—The marbles of Greece are remarkable for their history, having been used in some of the most famous sculpture of the world, among which might be included the celebrated tomb of Mausoleus, classed as one of the seven wonders of the world; the group known as the Farnese bull; and the original group of the Laocoōn in the Vatican at Rome. The great durability of these marbles is shown in the ruins of the Parthenon at Athens, where the pillars show no signs of decay after exposure of over 2000 years (A. Lee). This marble, like the Carrara, is a nearly pure carbonate of lime, but is more coarsely and brightly crystalline than the Italian marble; sculptors distinguish between the two in the broken pieces of statuary by the greater brightness of the Grecian. The quarries where it was formerly worked are in the Island of Paros (whence the name Parian marble) and Mount Pentelicus. The quarries were abandoned soon after the opening of the Italian quarries, but the Pentelic quarries have recently been reopened, and the attempt made to again bring it into the market. One writer† says the Italian marble is superior to the Grecian for

*For further particulars on Italian marbles see:

Mineral Resources of Italy, London.

Delesse, Materiaux de Construction.

A Visit to Carrara, by A. Lee.

Sir R. Murchison, in Quar. Jour. Geol. Soc., Vols. V. and VI., 1849 and 1850.

Marble and Marble Workers, by A. Lee.

Building and Ornamental Stones, by E. Hull.

Smithsonian Report, 1886, Part II., G. P. Merrill.

Robert Welch in Century Magazine for June, 1882, p. 240.

†A. Lee, Marble and Marble Workers, p. 80.

statuary purposes; another* claims that the Grecian marbles are far superior to the Italian.

Spain and Portugal.—Spain and Portugal produce many beautiful marbles; the one best known in the United States is the Lisbon marble, which, according to Newberry,† was one of the first colored marbles imported into the United States, and is now as extensively used as any other. Its prevailing color is pale red, traversed by thin dark veins, which inclose rounded spaces, giving it a coarsely mottled appearance. Professor Merrill‡ describes a Lisbon marble as a yellow variety from Estremoz, in color and texture almost identical with the celebrated Italian Sienna. Among other handsome varieties are the *rose des Pyrenees* from Spain, a finely mottled, pale and dark rose red, flecked and veined with white; the Emperor's red, a bright red colored marble; the St. Silvester, which is said to be one of the most beautiful marbles known; and the Gibraltar stone, which is a stalagmitic marble found in the caves of Gibraltar.

Austria.—Probably the best known Austrian marble is the Istrian, quarried at Istria, near Trieste. It is a light cream-colored, compact, and very durable stone. The Lumachelle, or the opalescent Lumachelle, is a fossiliferous marble in which the shells still retain their nacre or pearly lining, which gives the stone a brilliant iridescence.

Belgium.—The marbles of Belgium are not so abundant and varied as those of some other countries, but they are better known, because more industriously worked. One of the best known of the Belgian marbles is St. Anne's, which has a dark gray ground with lighter patches and is regularly veined and flowered with white.

The black marble of Belgium is noted as the finest known; it is a deep uniform black color, very hard, and is said to be diffi-

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*E. Hull, Building and Ornamental Stones.

J. S. Newberry, Trans. N. Y. Acad. Sci. Vol. III., p. 102, says that we have no substitute for the Pentelican marble.

†Report of Judges, U. S. International Exposition, 1876, Vol. III., p. 148.

‡Smithsonian Report, 1886, Part II., p. 483.

cult to work, but susceptible of a high polish. It is quarried at Golzinnes near La Bussiére, in the neighborhood of Dinant and near the French frontier. The Dinant marble is largely used in the manufacture of clock cases and tiles for flooring.

The red marbles of Belgium have a number of fancy names, of which *rouge griotte* has come to mean, in the English market, the best quality (Lee). The *rouge royal* is of a light color, somewhat resembling a variety of the Tennessee marble, but it is inferior in quality. Other varieties are the *blue Belgae*, *grande antique*, *petit antique*, *coquiller*, *jaune oriental* (said to be reddish brown instead of yellow), etc. The quarries in Belgium are better equipped with machinery than any others on the continent.

Sweden.—Sweden produces a crystalline white marble near Tayernach, and a black and white marble at Jemtland.

Norway.—A white marble is worked at Hegge, near the southern extremity of Vel Fiord.

Russia.—Quarries of gray, green and black, and red marbles are reported at several points in Russia; they are worked but little, and Russia imports most of her marble.

Africa.—Africa is celebrated for its Numidian marbles, which are said to have been great favorites with the Romans and largely used by them for interior decorations, the most famous variety being the renowned *Giallo Antico.* According to Playfair the marbles are incorrectly named, as they do not occur in Numidia proper, but in the provinces of Africa and Mauritania. He describes them as follows: "There on top of the *Montagne Grise* exists an elevated plateau, 1500 acres in extent, forming an uninterrupted mass of the most splendid marbles and breccias which the world contains. Their variety is as extraordinary as their beauty. There is a creamy white, like ivory; rose color, like coral; Giallo Antico. Some are as variegated as a peacock's plumage, and on the west side of the mountain, where there has been great earth movement, the rock has been broken up and recemented together, forming a variety of breccia of the most extraordinary richness and beauty."* The knowledge

*Geological Magazine, London, December, 1885.

of the source of these beautiful marbles was lost for many centuries, but they were rediscovered by a Belgian engineer, and are now worked by a Belgian company.

The so-called "Egyptian onyx" is a beautiful stalagmitic marble which was largely used in Rome and Carthage for interior decoration. This marble was rediscovered in 1849 by a Frenchman, M. Delmonte, in the Blad Recam (Marble Country) near the ravine of Oned-Abdallah, after a lapse of 1000 years from the time it was worked by the Romans.* It is now shipped to Paris and the United States, where it is used for ornamental purposes. Oriental alabaster is another variety of the stalagmitic marble, sometimes used synonymously with the "onyx," and is as much of a misnomer. The "Algerian onyx" is a stone of similar formation from Ain Tekbalet, near Tlemcen.† Prof. Merrill considers this stone inferior to the Egyptian variety. The nummulitic limestones, abundant in North Africa, are used in places as marble. The *breccia di verde*, a beautiful marble, is found between the Nile and the Red Sea.

Asia.—The Phrygian marble or "Pavonazetta," much used in Southern Italy, is said to be‡ one of the most curious and handsome marbles in the market.

In Palestine marbles were used extensively in the building of Solomon's temple and palace.‖ The situation of these quarries is not known.

Persepolis, the ancient capital of Persia, contains slabs of marble of great beauty, taken, it is said, from the neighboring mountains. In Ispahan, the modern capital, both white and colored marbles are used.

In India several varieties of marble have been worked; the most noted perhaps being the Makrana, a white crystalline marble quarried near Jodphur, Rajputana.

Japan.—A variety of marbles and other stones, suitable for

*E. Hull, Building and Ornamental Stones.

†So given by A. Lee in Marble and Marble Workers, p. 91; while Prof. Merrill gives it Ain Tembalek in the province of Oran.

‡Hull, Building and Ornamental Stones, p. 143.

‖I. Chronicles, XXIX.; Josephus, Book VIII., Sec. 3.

decorative purposes, is found in Japan in Mino and Hitachi provinces.*

Australia.—There are several varieties of marble in Australia which have been quarried recently. There is a red fossilized marble resembling the Derbyshire marbles of England; mottled green and black marble; a white marble; a dark purple and red marble; heavy beds of coralline marbles of various colors—white, cream, dove-colored, and pink; a white, light blue-veined marble; and a pure white crystalline marble.†

Antique marbles.—The name of antique marble is frequently given to the marbles found in the old Roman and Greek ruins. Many handsome varieties found there in abundance are now quarried, as the Pentelican, Carrara, Phrygian, Giallo Antico, and others, while the sources of many others are unknown. Newberry says‡ the finest collection of marbles could be made not from the quarries but from the old ruins, and that one collector has a thousand varieties of marble obtained from the ruins of Rome. A description of these rare and beautiful marbles would be interesting, but does not come within the province of the present work.

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*Smithsonian Report, 1886; Part II., p. 482.

†A. Lee, Marble and Marble Workers, p. 99.

‡Transactions New York Academy of Science, Vol. III., p. 102.

CHAPTER XV.

The Marbles of Arkansas.

LITERATURE, DEVELOPMENT, VARIETIES, AND ANALYSES.

Literature on the marbles of Arkansas.—While the newspapers of the state have had numerous articles on the marbles of North Arkansas,* the scientific information extant on the subject is very limited.

The first mention of the marbles in any scientific work was made by Henry Schoolcraft, in 1819. In two places† in enumerating the minerals found in this territory he mentions marble, but he gives no descriptions or exact locations.

Dr. D. D. Owen, a former State Geologist, in his report‡ on North Arkansas says: "Near the junction of the subcarboniferous limestone and the saccharoidal sandstone, overlying the lower magnesian limestones, there are encrinital, mottled, and variegated limestones, which take a good polish, and will make, at many localities, a fine marble rock, particularly near the corner of Carroll,|| Newton, and Searcy counties." In another place (p. 87), Dr. Owen speaks of a block being sent to the Washington Monument, and of seeing a slab for a currier's table at Yardell. He also speaks of the color of the marble on Davis Creek (p. 88) as apparently due to manganese, but a del-

*Probably the best newspaper articles which have been published on this subject are a series of letters to the Arkansas Gazette, written by Col. M. L. De Mahler and signed "Potomac." These letters were published in 1885, those relating more particularly to the marble, bearing the dates June 23 and July 2.

†A View of the Lead Mines of Missouri; including some observations on the Mineralogy, Geology, Geography, Antiquities, Soil, Climate, Population, and Productions of Missouri and Arkansaw, and other sections of the western country, by Henry R. Schoolcraft, N. Y., 1819, pp. 44 and 251.

‡First Report of a Geological Reconnoissance of the Northern Counties of Arkansas, 1857-1858, by Dr. D. D. Owen, p. 137.

||Boone county has been formed since that time and the reference Dr. Owen here makes to Carroll now applies to Boone county.

icate chemical analysis showed no manganese present. In another place (p. 45) he speaks of the encrinital marble of Marion county.*

In Dr. Owen's second report (p. 406), Prof. E. T. Cox, assistant geologist, says: "Ascending to the headwaters of Keel's Creek, in Madison county, we saw the pink and gray marble rock exhibited in great perfection. One slab, which lay across our road, was six inches thick, and from twelve to fifteen feet across in any direction. At this place it could easily be quarried, and obtained in enormous, perfect slabs."

Prof. F. L. Harvey in a catalogue of the minerals and rocks of Arkansas says:† "Encrinital marbles of a fine red and gray color occur in large deposits in Marion, Carroll, Newton, and Searcy counties. The encrinite discs are usually white in a red matrix giving a beautiful effect. Black marbles of various shades occur in Independence, Van Buren, and Searcy counties. The black color is due to organic matter. The marbles of Arkansas perhaps would be more strictly classed as compact limestones."

In the catalogue of exhibits at the International Exhibition at Philadelphia, 1876, mention is made (p. 27) of black marble, brecciated marble, four specimens of different colors, and a lithographic stone, in the mineral exhibit from the line of the St. Louis, Iron Mountain & Southern Railway.

In the report on the New Orleans Exposition‡ is the statement that: "Immense quantities of marble, pink and gray, are being operated in several counties, notably in Madison."

Mention is made of marble in the state in the following pamphlets, but no description is given: Natural Resources of

*Brief mention is made of the marbles by Dr. Owen in several other places in his report; but as he only made a hasty reconnoissance of the region, he does little more than make mention of the marble along with the other things he saw.

†The Minerals and Rocks of Arkansas.—A Catalogue of the Species, with Localities and Notes, by F. L. Harvey, Pub. by Grant & Faires, Philadelphia, 1886, p. 20.

‡Arkansas Exhibit at the World's Industrial and Cotton Centennial Exposition, 1884-1885, at New Orleans, La., compiled by Hon. C. M. Taylor, U. S. Commissioner, p. 4.

the State of Arkansas, by James M. Lewis, 1869, p. 18; Resources of the State of Arkansas with description of Counties, Railroads, Mines and the City of Little Rock, by James P. Henry, 1872, p. 33; Products and Resources of Arkansas, compiled by D. McRae, by direction of Hon. S. P. Hughes, Governor of Arkansas, 1885, p. 12.

In Mineral Resources of the United States for 1888, p. 542, occurs the statement that in Searcy county there is a fine gray marble easily worked and capable of a beautiful polish.

Dr. J. C. Branner, the State Geologist, in an article on the Building Stones of Arkansas, published in 1889,* makes brief mention of the occurrence of the marbles in North Arkansas.

Dr. R. A. F. Penrose, Jr., in Vol. I. of the Annual Report of the Geological Survey of Arkansas for 1890, describes in detail the geology of the eastern part of the marble area in Independence, parts of Izard and Stone counties, and describes one of the principal beds of marble (the St. Clair) in its geologic relation to the other rocks of the region, but discusses its economic features only in so far as they bear on the manganese ores.

It will thus be seen that the published information in regard to the Arkansas marbles is brief and fragmentary.

Development of the marbles of Arkansas.—Comparatively little work has been done to develop the marbles and bring them into the market. Probably the first piece of marble shipped out of the state was the one sent to the Washington Monument in 1836, the year in which the state was admitted to the Union. The block, weighing 9000 pounds, was taken from near Marble City, Newton county, then known as Beller's Mill. It was obtained by Mr. Beller and Elijah, Samuel, and William Harp. By drilling and wedging they separated the block from a ledge four feet thick. It was then put on a log wagon and with ten yoke of cattle these four men took the stone a distance of sixty miles or more over exceedingly rough and tortuous roads across the Boston Mountains to the Arkansas River near Clarksville, whence it was shipped by boat.

*Stone, Vol. II., No. 6, October, 1889.

The Arkansas Marble Company has shipped numerous samples from its property at St. Joe, Searcy county, to St. Louis and to Little Rock, where they have attracted attention.

In 1885, Mr. E. J. Rhodes, of Boone county, sent several polished samples to the Exposition at New Orleans, for which he received a diploma.

The marbles of Arkansas have had but a limited local use. Mr. Nick Miller, whose headquarters are at Harrison, has worked tombstones and arch rocks for chimneys out of the native marble in Boone, Marion, and Newton counties. He also put a marble front in one of the store buildings in Yellville, the county seat of Marion county. Mr. Lee Randolph has worked for several years in the native marble at Marble City, Newton county, most of his work being in tombstones. Near Yardell, Newton county, Mr. Jones has made a number of tombstones of the marble in that vicinity. Mr. Calvin Somers, at Sylva (De Soto Springs), Marion county, has for many years worked at intervals on the marble of that and adjoining regions, making it into tombstones, table tops, and arch rocks. At Batesville, Independence county, Mr. H. J. Wiebusch has made a number of monuments out of the marble in that vicinity.

In various places throughout the marble area marble has been used for building chimneys, foundations, spring-houses, and similar purposes. One of the business houses at Harrison is partly faced with it, and Mr. Wilson, who lives a mile east of Harrison on the south side of Crooked Creek, has built a neat dwelling-house out of marble quarried at the house. The new bank building at Batesville has a front of native marble.

At Eureka Springs it has been used to decorate the interior of the Crescent Hotel, and in ornamenting the Grotto spring and the pavilion near the Crescent spring. At the same place it has also been used extensively for building purposes, such as retaining walls along Spring street, for basements and for sidewalls in several of the houses on Mud street. The large arches over the ravines on the boulevard near the new

Sanitarium building are constructed of red marble quarried on the grounds.

Varieties of Arkansas marble.—The marbles of Arkansas all belong to the list of colored marbles; although some of them are very light colored, all are more or less stained with metallic oxides or with carbonaceous matter. On a stratigraphic basis all the numerous varieties of marble in Arkansas are, with very few exceptions, included in three classes: the St. Clair; the St. Joe; and the gray marble of the Boone chert formation. The first of these, the St. Clair marble, occurs over the eastern and south central part of the area, and is of Silurian age. The St. Joe and gray marbles, occurring over the entire area, are at the base of the Lower Carboniferous rocks. The few varieties which do not occur in any of these classes are the black, yellow, "onyx," and Archimedes marbles.

Comparison of the strength, weight, and absorption of Arkansas marbles with those of other building stones.

Number.	Kind of stone.	Locality.	Crushing strength per square inch.	Specific gravity.	Weight per cubic foot.	Ratio of absorption.
1	St. Joe marble	St. Joe, Ark	17,835	2.712	169.50	0.34
2	St. Joe marble	St. Joe, Ark	10,447	2.697	168.56	.38
3	St. Joe marble	St. Joe, Ark	11,265	2.707	169.19	.25
4	St. Joe marble	Marble City, Ark	8,984	2.691	168.19	.57
5	St. Joe marble	Marble City, Ark	10,381	2.686	167.88	.49
6	St. Joe marble	Rhodes' Mill, Ark	14,400	2.711	169.44	.29
7	St. Joe marble	Rhodes' Mill, Ark	15,780	2.715	169.69	.15
8	St. Clair marble	St. Joe, Ark	6,728	2.693	168.31	.37
9	St. Clair marble	St. Joe, Ark	8,408	2.707	169.19	.38
10	Boone chert limestone	St. Joe, Ark	6,935	2.675	167.19	.56
11	MARBLE	MONTGOMERY CO., PA	13,700			
12	MARBLE	MONTGOMERY CO., PA	10,940			
18	MARBLE	VERMONT	18,400			
14	MARBLE	DORSET, VT	8,670	2.683	167.8	
15	MARBLE	DORSET, VT	7,612	2.635	164.7	0.58
16	CARRARA MARBLE	ITALY	12,156	2.690	168.2	
16	DOLOMITE	TUCKAHOE, N. Y	18,076	2.887	177.6	
18	DOLOMITE	LEE, MASS	22,860			
19	MARBLE	COLTON, CAL	17,783	2.750	172.06	
20	MARBLE	CANAAN, CONN	5,812			
21	OOLITIC LIMESTONE	ELLETTSVILLE, IND	13,500		142.23	3.57
22	OOLITIC LIMESTONE	BEDFORD, IND	6,500		147.03	4.12
23	OOLITIC LIMESTONE	BEDFORD, IND	10,125		152.39	3.12
24	OOLITIC LIMESTONE	SALEM, IND	8,625		144.28	4.55
25	LIMESTONE	QUINCY, ILL	9,687	2.570	160.6	.55
26	DOLOMITE	LEMONT, ILL	12,000	2.645	165.3	1.12
27	DOLOMITE	JOLIET, ILL	14,775	2.560	160.0	1.06
28	DOLOMITIC LIMESTONE	RED WING, MINN	23,000	2.595	162.2	2.50
29	DOLOMITIC LIMESTONE	STILLWATER, MINN	10,750	2.567	160.4	2.50
30	LIMESTONE	BILLINGSVILLE, MO	6,650	2.820	145.0	4.35
31	CAEN LIMESTONE	FRANCE	3,650	1.900	118.8	5.26
32	Light blue granite	Little Rock, Ark	33,620	2.659	166.0	.08

Composition of Arkansas marbles and limestones compared with that of other building stones.

Number.	Kind of stone.	Locality.	Carbonate of lime.	Carb'te of magnesia.	Silica.	Alumina.	Ferric oxide.
			Pr. ct.	Pr. ct.	Pr. ct.	Pr. ct.	Pr. ct.
1	St. Clair marble	St. Clair Springs, Ark	97.77	....	.54	.18	.19
2	St. Clair marble	Hell Creek, Ark	98.40	trace	.82	.10	.80
3	St. Clair marble	Cason property, Ark	98.90	.23	.45	.28	.14
4	St. Clair marble	Nale property, Ark	98.04	1.09	.46	.16	.25
5	St. Clair marble	Brooks Mine, Ark	97.88	.50	.73	.24	.11
6	St. Clair marble	Polk Bayou, Ark	97.86	.61	.25	.37	.56
7	St. Clair marble	Polk Bayou, Ark	98.42	.51	.69	.10	.17
8	St. Clair marble	Cole property, Ark	97.39	.53	.54	.06	.24
9	St. Clair marble	St. Joe, Ark	99.68	trace	.11*	....	.08
10	St. Clair marble	Maxfield property, Ark	92.18	.58	1.00	.61	2.49
11	St. Clair marble	Penter's Bluff, Ark	95.88	....	2.46*	....	
12	St. Clair marble	N. Sylamore, Ark	92.91	1.07	1.94	.62	2.98
13	St. Joe marble	Marble City, Ark	98.71	.40	.80*	.01	.05
14	St. Joe marble	Rhodes' Mill, Ark	98.72	.34	.84*	.02	.06
15	St. Joe marble	St. Joe, Ark	98.73	....	1.16*	....	
16	St. Joe marble	Tomahawk Creek, Ark	95.46	.97	2.43	.36	1.05
17	St. Joe marble	Flat Rock, Ark	99.80	....	.20	....	
18	WHITE MARBLE	PROCTOR, VT	96.30	3.06	.63*	....	.04
19	GEORGIA MARBLE	GEORGIA	97.32	1.60	.62	.25	.26
20	TENNESSEE MARBLE	KNOXVILLE, TENN	98.43	.30	.39*	.31†	
21	TENNESSEE MARBLE	CRESCENT QUARRY, TENN	98.77	.42	.13	trace	.26
22	ITALIAN MARBLE	CARRARA, ITALY	98.77	.90	.16	.08†	
23	VERMONT MARBLE	SWANTON, VT	94.66	.23	2.39*	1.09†	
24	MARBLE	GOUVERNEUR, N. Y	92.09	6.90	1.39	....	
25	Chert limestone	Victor, Ark	98.59	.82	.68	....	.82
26	Chert limestone	Allen's Quarry, Ark	98.25	trace	1.61	....	.14
27	Chert limestone	Jones' Quarry, Ark	95.82	....	4.38*	....	
28	Chert limestone	Loster's Spring, Ark	98.07	....	1.47	....	
29	Chert limestone	Denieville, Ark	98.43	.95	.28	....	
30	Izard limestone	Polk Bayou, Ark	97.97	....	1.44	....	
31	Izard limestone	Lafferty Creek, Ark	98.67	2.14	.34	....	.07†
32	Oolitic limestone	Brush Creek, Ark	98.38	....	.50	....	
33	Oolitic limestone	War Eagle Creek, Ark	99.81	....	.19	....	
34	Chert limestone	Pond Mountain, Ark	98.32	.03	....	....	
35	Chert limestone	Rogers lime-kiln, Ark	98.02	.07	....	....	
36	Chert limestone	Mill Creek, Ark	99.25	....	.30*	....	.06
37	Dolomite (cotton rock)	Caney Creek, Ark	56.58	34.69	8.01*	....	1.21†
38	Dolomite (cotton rock)	Baxter county, Ark	48.23	38.36	13.52*	....	.89†
39	Dolomite (cotton rock)	Waldon, Ark	49.47	40.85	....	....	
40	Dolomite (cotton rock)	Leatherwood, Ark	47.91	39.23	8.65	....	
41	Dolomite (cotton rock)	Leatherwood, Ark	49.53	40.00	....	4.72	
42	Dolomite (cotton rock)	19 N., 17 W., sec. 17, Ark	49.89	37.21	....	....	
43	Dolomite (cotton rock)	19 N., 17 W., sec. 7, Ark	82.25	24.02	....	....	
44	Dolomite (cotton rock)	19 N., 18 W., sec. 11, Ark	48.22	37.89	12.76	....	
45	Dolomite (cotton rock)	Eureka Springs, Ark	47.43	35.76	14.71	....	
46	Dolomite (cotton rock)	Yellville, Ark	48.53	37.91	12.07	....	
47	WATER-LIME ROCK	NEW YORK	48.04	34.03	13.85	....	1.75
48	DOLOMITE	RED WING, MINN	49.16	37.53	13.06*	....	1.09
49	MARBLE (DOLOMITE)	TUCKAHOE, N. Y	54.49	43.62	.91*	....	
50	OOLITIC LIMESTONE	BEDFORD, IND	96.60	.13	.50	....	.98

*Residue insoluble in acid.
†Alumina and iron oxide.

CHAPTER XVI.

The St. Clair Marble.*

Stratigraphy.—The St. Clair marble, named from St. Clair Springs,† northeast of Batesville, is one of the thickest and most important beds of marble in the state. It is underlain by the amorphous blue Izard limestone and is overlain by the Sylamore sandstone or the Eureka shale, one or both of which are generally present, but often in an inconspicuous bed only a a few inches in thickness. In the absence of both the Sylamore sandstone and the Eureka shale the St. Clair marble is overlain by the St. Joe marble, which forms the base of the Boone chert formation. As all the overlying formations have been determined to be Lower Carboniferous (or Devonian?), and the St. Clair marble to be Silurian, it thus forms the top of the Silurian where it occurs.

As the Sylamore sandstone and Eureka Shale will be mentioned frequently in the following chapters as marking the upper limit of the St. Clair marble, or the bottom of the St. Joe, or the separation of the two marbles, a briet description of them is here given.

The Sylamore sandstone is generally an insignificant bed, being often but a few inches in thickness and readily disintegrating, so that it is frequently overlooked even when present. It differs greatly in character in different parts of the area; in some places it is made up of rounded grains of hard crystalline

*To avoid repetition of words the term marble is here used to designate a certain geologic formation. Much beautiful marble occurs in this bed, but it is by no means all marble; and while it would be more nearly correct to speak of the entire formation as the St. Clair limestone, and to call it marble where it is marble, it is more convenient to use the term marble to include the whole bed.

†The name was proposed as a provisional one by the State Geologist, and was first used in the Survey's reports by Dr. Penrose in Vol. I., of the Annual Report for 1890.

quartz, interspersed with black, rounded, irregular pebbles; in other places it is a soft, earthy rock of a yellowish brown color; in still other places an arenaceous shale. The dark colored pebbles are a peculiar feature of this rock, yet they are not always present. In a few places it forms a bed of considerable thickness; thus on Blowing Cave Creek, west of Cushman, and in one place on South Sylamore, it is fully forty feet thick.

The Eureka shale occurs at the same horizon as the Sylamore sandstone, and is generally present in the absence of the sandstone, while in some places both sandstone and shale are present. However, in a general way, the sandstone occurs in the eastern part of the area and the shale in the western part. Where typically developed, the Eureka shale is a black, pyritiferous, argillaceous shale. The maximum thickness observed for this bed is fifty feet, the average thickness being about four or five feet. Like the Sylamore sandstone, its chief interest lies in its position, marking, as it does, the division between the Carboniferous and Silurian.* (See Plate X.)

Paleontology.—The St. Clair marble is fossiliferous throughout the greater part of its extent. Dr. Henry S. Williams has determined fossils from this bed in some places to represent Trenton fauna, in other places, Niagara; and he classifies it from paleontologic evidence as belonging to a horizon between the Trenton and Niagara groups of the New York section.†

The best localities for collecting fossils from the St. Clair marble are at St. Clair Springs; on the east side of Polk Bayou just above the first ford of the Bayou on the wagon road north from Batesville; in 14 N., 6 W., section 34, at the Cason place;

*Both these formations will be described in detail in a subsequent volume of the Survey reports. See also, Proceedings of the American Association for the Advancement of Science, Vol XL., 1891, p. 256.

†Letter to the State Geologist, December 1, 1890.

In a letter received after the above was in type and after a recent examination of fossils from the Batesville region, he says that the manganese horizon marks the top of the Trenton and that the part of the marble bed overlying the manganese, as shown at the Cason place and the O'Flinn mine, is Niagara.

at the O'Flinn mine, 14 N., 6 W., section 22; on Mill Creek, Stone county, 15 N., 11 W., section 5; on the south side of Roasting-ear Creek just above Mr. Norman's house, in 15 N., 13 W., section 1. Fossils occur at many other localities.*

Thickness of the St. Clair marble.—The thickness of the bed varies from zero to more than 150 feet. The maximum thickness, which is 155 feet or more, is at Penter's Bluff on White River. It thins out gradually towards the east, west, and north; on Polk Bayou it is probably not more than 100 feet thick, while on Dota Creek, still further east near the Paleozoic border, it does not occur at all. Above the mouth of Hidden Creek on White River, it is 50 feet thick; but a few miles further up the river, below the mouth of Twin Creek, there is only a trace of the marble. On the south side of White River, on Little Rocky Bayou, it is from 25 to 40 feet thick; on South Sylamore it is from 25 to 50 feet thick, and at St. Joe it is from 20 to 30 feet thick. There are local changes of thickness between the points named, due in part, no doubt, to the decay of the marble. (See Plates III. and IV.)

Color of the St. Clair marble.—The color of the St. Clair marble varies in different localities from a light gray to a dark chocolate-brown. The prevailing color is a light gray with a tinge of pink. The brightest colored variety found is nearly red, and occurs on North Sylamore and on Roasting-ear Creeks. In the manganese region it is in many places stained a deep chocolate color by the manganese and iron oxides contained therein, from which it varies through all intervening shades to the light gray. The following analyses† of differently colored samples of St. Clair marble show that the deep colored varieties have a greater percentage of metallic oxides:

* A descriptive list of fossils and other details on the paleontology will be published in a future volume of the Survey's publications.

†Volume I. of the Annual Report for 1890, p. 173.

Analyses of differently colored St. Clair marbles.

Constituents.	Chocolate-brown.	Chocolate-brown.	Pink.	Gray.
Manganese oxide (Mn_3O_4)......	1.59	1.24	0.26	trace.
Ferric oxide (Fe_2O_3)............	0.56	2.49	0.19	0.24
Alumina (Al_2O_3)...............	0.37	0.61	0.18	0.06
Lime (CaO)...................	54.75	51.62	54.70	54.76
Magnesia (MgO)	0.29	0.28	....	0.25
Potash (K_2O)	0.01	0.02	0.78*	0.78*
Soda (Na_2O)..................	0.25	0.31		
Volatile matter†	42.31	42.46	43.35	43.19
Silica (SiO_2)	0.25	1.00	0.54	0.54
Total	100.38	100.03	100.00	100.00

These analyses show that the color of the marble is produced by manganese and iron oxides; the depth of color, however, does not depend so much on the amount of coloring material as on the state in which it occurs and the manner in which it is diffused through the rock.

Texture of the St. Clair marble.—In general the St. Clair marble is highly crystalline, composed of small crystals of a nearly uniform size, ranging from one to two fortieths of an inch in diameter. There are local variations in which the separate crystals are larger. It is tenacious, easily cut, but breaks with difficulty, and has a slightly conchoidal fracture. In weathering, the crystals are separated; the long exposed surfaces are often covered to a depth of a quarter of an inch or more with a granular mass of separated crystals resembling coarse sand.

Gross structure of the formation.—The St. Clair marble commonly outcrops in heavy stratified layers from two to four feet and more in thickness; but it is in some places massive, the entire exposure being in one solid massive bed. It is not improbable that the greater part of the bed will be found to be massive in the interior beyond the reach of weathering influ-

*Determined by difference.

†The volatile matter is mostly carbonic acid and some water. There is only a small quantity of organic matter present in any of the specimens, and in some of them there is none. It does not appear to have perceptibly influenced the color, which is still retained after ignition.

ences, as apparently the oldest exposures show the greatest number of stratification planes, while the more massive exposures are in bluffs along more recently cut watercourses. In some places it exfoliates on the weathered surface, peeling off in flakes nearly parallel with the slope of the hill and quite independent of the bedding planes.

Density of the St. Clair marble.—Although not so dense as some varieties of the St. Joe marble, yet it is a dense, compact rock as shown by the following specific gravity tests.

Specific gravity and weight of St. Clair marble.

Sample from	Specific gravity.	Weight in lbs. per cu. ft.
1. Brooks' mine, Independence county..........	2.6910	168.19
2. Hell Creek, Stone county..................	2.6816	167.60
3. St. Joe, Searcy county......................	2.6912	168.20
4. St. Joe, Searcy county......................	2.6926	168.29
5. St. Joe, Searcy county......................	2.7067	169.17
6. Crescent quarry, E. Tenn..................	2.6917	168.23
Average of first three....................	2.6879	168.00
Average of first five......................	2.6926	168.29

The specific gravities of the first three samples were determined from single specimens by Gillmore's method on a Jolly balance by Mr. E. J. Emmert.

The specific gravities of numbers 4 and 5 were determined by the common method with Jolly balance, and each result is the average of ten samples.

Number 6 was determined in the same way and in the same place as the first three and is given here for comparison, as it so closely resembles the St. Clair marble in appearance, and, so far as known, in geologic position. It will be noticed how closely it corresponds in density with the St. Clair marble.

The weight of water was assumed in each case to be 62.5 lbs. per cubic foot.

All the samples were of necessity taken from the surface exposures and were probably affected to some extent by atmospheric agencies.

Composition of the St. Clair marble.—The St. Clair marble varies in composition in different parts of the bed; as shown

in Vol. I. of the Annual Report for 1890, in the manganese area it locally contains a variable percentage of manganese and other impurities. Except where deeply stained with manganese and iron it is a remarkably pure carbonate of lime.

Analyses of St. Clair marble.

	Brook's Mine. Per cent.	Hell Creek. Per cent.	St. Joe Per cent.	St. Clair Springs. Per cent.	Lower Polk Bayou. Per cent.
Lime (CaO)	54.82	55.74	56.22	54.70	55.21
Manganese oxide (MnO_2)	0.15	......	......	0.26	.....
Iron oxide (Fe_2O_3)	0.11	0.30	0.08	0.19	.27
Silica (SiO_2)	0.73	0.32	0.11	0.54	.69
Alumina (Al_2O_3)	0.24	0.10	......	0.18	.10
Magnesia (MgO	0.24	trace	trace	0.78	.27
Potash (K_2O)	0.01	0.17	0.07		tracé
Soda (Na_2O)	0.48	0.22	0.08		
Phosphoric acid (P_2O_5)	.....	0.49	......	......	.35
Loss on ignition (CO_2 etc.)	43.08	43.31	43.79	43.35	43.39
Total	99.86	100.65	100.31	100.00	100.28
Water at 110°—115° C.	0.09	0.059	0.04	0.04	98.42
Carbonate of lime ($CaCO_3$)	97.88	98.40	99.68	97.77	

It will be noticed that the sample from St. Joe comes nearer a pure lime carbonate than the others, showing less than one half of one per cent. of impurities; it is likewise the most durable in appearance. However, in numerous other localities both in and out of the manganese area, the marble is to all appearances equally pure and durable.

For comparison the analysis of a sample of Tennessee marble is also given in this place.

*Analysis of marble from Crescent Quarry, E. Tennessee.**

	Per cent.
Lime (CaO)	55.32
Iron oxide (Fe_2O_3)	0.26
Silica (SiO_2)	0.125
Alumina (Al_2O_3)	trace
Magnesia (MgO)	0.02
Sulphur (S)	0.005
Carbonic acid (CO_2)	43.51
Water (H_2O)	0.13
Organic matter and loss	0.63
Total	100.00

*From Mineral Resources of the United States, 1888, p. 543. Analysis made at the Columbia College School of Mines.

Partial analyses of St. Clair marbles.

Sample from	Carbonate of lime ($CaCO_3$).
14 N., 6 W., section 34	99.23 per cent.
Lafferty Creek (impurities 1.19 per cent.)	98.90 per cent.
Penter's Bluff, White River	95.88 per cent.

Strength.—The St. Clair marble can be cut, ground, or powdered with comparative ease; but in large pieces it breaks with difficulty. No tests have been made on the transverse strength, in which respect it is apparently superior to many of the other marbles of the state. In resisting a crushing force it is inferior to the St. Joe marble, and as shown by experiment, approximately the same as the coarsely crystalline gray marble of the Boone chert. The samples used were necessarily taken from surface boulders.

Crushing strength of St. Clair marble from Mill Creek, St. Joe, Arkansas.

No.	Height of cube. Inches.	Crushing area of cube. Sq. in.	Crushing weight in pounds.	Crushing weight per sq. in.
1	1.515	2.235	16,370	7,324
2	1.442	2.278	14,250	6,260
3	1.493	2.289	15,100	6,600
4	1.485	2.296	16,800	7,320
5	1.529	2.288	14,600	6,380
6	1.594	2.256	21,550	9,550
7	1.500	2.274	22,250	9,790
8	1.508	2.293	20,600	9,000

Average strength per square inch 7,778

Average strength per square inch of last three 9,447

The first five samples were bedded in plaster of Paris, the last three were simply wet and rubbed with plaster of Paris, which evidently accounts for the wide difference in result between the last three and the preceding ones.

The results show the St. Clair marble to have about the same crushing strength as two samples of Vermont marble tested by Gen. Gillmore, but weaker than the majority of marbles.*

Absorption tests.—The long-exposed, much-weathered sur-

*For comparison, see report by Q. A. Gillmore in appendix to the Annual Report of the Chief of Engineers, for 1875, U. S. A., or the tables on p. 210.

face of the St. Clair marble is very porous, but samples from the interior of even the surface boulders show the absorption to be very small.

Absorption tests of St. Clair marble from Mill Creek, St. Joe, Arkansas.

Number.	Original weight.	Dry weight.	Weight after being in the water				Dry weight.	Ratio of absorption.	Percentage of absorption.
			3 hrs.	1 day.	3 days.	60 days.			
1	155.225	155.082	....	....	155.320	155.435	155.070	1-425	.24
2	62.900	62.765	62.939	62.941	62.913	63.007	62.770	1-265	.38
3	53.780	53.643	53.862	53.845	53.814	53.889	53.632	1-209	.48
4	133.598	133.471	....	....	133.780	133.860	133.477	1-349	.28
5	69.091	69.021	69.199	96.259	69.198	69.289	69.038	1-275	.36
6	38.454	38.383	38.515	38.521	38.490	38.540	38.398	1-270	.37
Average	....	....	....	....	....	....	....	1-299	.35

For making the tests pieces of different shapes were used, varying from cubes to thin strips. By original weight is meant the weight of the specimen as it came from the quarry; and dry weight is the weight after drying an hour or more at a temperature of 225° F. It is remarkable that at the end of three days the stone is lighter than after three hours, one day, or sixty days; the reason for this is not apparent.

The absorption is very low, the maximum being less than one half of one per cent., and the minimum less than a quarter of one per cent.

Resistance to fire.—By the citizens living in North Arkansas the St. Clair marble is regarded as a fire-proof rock, and is used to line fireplaces and fire-boxes of engine boilers. So far as could be ascertained by inquiry, it resists the action of fire better than any other rock in the region where it occurs, and it is hauled long distances to line fireplaces. For determining its fire-resisting properties the following test was made: a small piece of each specimen was placed in a bath of molten lead until a uniform temperature of about 600° F. was reached (twenty minutes were taken for a piece of stone weighing 100 grammes), and then suddenly cooled by plunging it in cold water. All of the specimens cracked badly and crumbled easily in the fingers at the edges where the stone was thinnest.

No weights to determine the loss of volume by this test were taken, as the stone showed unmistakable signs of injury. It is to be regretted that no other marbles were tried at the time by the same method.

Durability.—Much that has already been said about the St. Clair marble should be considered as throwing more or less light on its durability. The analyses show that outside of the manganese mines it is a remarkably pure carbonate of lime, which, so far as composition is concerned, if kept from contact with acids, is one of the most stable of compounds. The only substances in it liable to rapid decomposition to the injury of the stone are alumina and the alkalies (soda and potash), which are in such minute quantities as to render no injury. The specific gravity shows it to be of average density and compactness, and the absorption tests show it to be above the average in this respect.

Tests of two kinds were made upon the stone to show its resistance to the action of frost:

1. The pieces used for absorption tests were taken from the water, dried, weighed, placed in the water and allowed to remain there for six hours; then exposed alternately to freezing and to thawing under water six times, or a total exposure to freezing of ten hours at an average temperature of air of about 20° F., and a total thawing exposure in water of 100 hours, at an average temperature of water of 40° F. The freezing took place in each instance soon after exposure, and before much of the surface water had evaporated. Ice crystals were found attached to the specimens in each instance. At the end of the experiment the pieces were again dried as before and weighed, but no loss of weight due to crumbling from the action of frost could be detected.

2. Brard's test. Three small pieces of each of two specimens were placed in a saturated solution of sulphate of soda and boiled for one hour. They were then placed in a coarse sieve and exposed to the air at an average temperature of 70° F. for seventy-two hours (three days), then placed in clear boiling water and boiled for one hour, and finally dried in the oven

at 225° F. The efflorescing of the salt with which the stones were saturated represents in a measure the action of frost.

Brard's frost test of St. Clair marble.

No.	Weight before boiling.	Weight after boiling.	Loss.	Loss per cent.
1.	155.070	154.836	.234	.15
2.	62.777	62.594	.183	.29
3.	53.632	53.067	.565	1.05
4.	133.477	133.168	.309	.23
5.	69.039	68.575	.463	.67
6.	38.398	38.256	.142	.36
Average of the six				.46

The examination of marble used for tombstones and in old buildings often throws much light on its durability. Such information cannot be had, however, in regard to the St. Clair marble, because so far as known no such uses have been made of this rock. The reason for this probably lies in the fact that it occurs only in massive beds, which renders it difficult to obtain blocks of the desired size with the crude tools at hand.

The only other aid to a knowledge of its durability is from its weathered exposures. On the perpendicular faces of the bluffs the rock is weather stained, but generally solid almost to the surface, and frequently so firm, compact, and even, as to make it difficult to find a projecting corner or prominence from which one can chip a fragment with a hand hammer. Unlike the St. Joe marble and the Izard limestone, it does not present sharp corners. On the sloping hillsides weathering has produced large, partly rounded boulders from one foot to thirty feet in diameter; these boulders are frequently disintegrated to a depth of several inches, the outside of the rock consisting of a loose aggregation of calcite crystals. To a person familiar with the glaciated surfaces of the northern United States, this decayed surface might condemn the stone at once. But it should be remembered that we now see the stone after its exposure to atmospheric influences for an enormous length of time without the wearing action of ice to clean away the decayed material. It is true that the Izard limestone underlying the St. Clair marble in many, probably most, of its exposures, has a firm,

compact surface with square corners at the bedding and joint-planes; on the other hand the granites and syenites of Pulaski and Saline counties present a disintegrated surface not unlike that of the St. Clair marble; in fact, at a distance the resemblance between the weathered exposures of the granite and the St. Clair marble is remarkable.

The explanation of the disintegrated surface of the marble and syenite is found in the great durability of the separate crystals. A fine-grained, non-crystalline limestone, like the Izard limestone, on decomposing, is washed away by the rains, as there are no large particles. But in a coarsely crystalline stone the cementing material is generally the first to give way, leaving the separate crystals free, which, being too heavy to be carried away by the water, remain as a loose mass on the surface of the rock.

Adaptability of the St. Clair marble.—The St. Clair marble, because of its soft pleasing colors, the great thickness of the bed, and the admirable position in which it lies for quarrying, is a valuable building stone. As stated, the stone varies in color, yet the greater part of it and the most valuable part of it has a light gray color with a faint tinge of pink given it by numerous pink crystals among the gray. In color and general appearance it closely resembles the marble from the Crescent quarry near Knoxville, Tennessee; also that quarried at the confluence of the French Broad and Holston Rivers near Knoxville, of which the post-office in Knoxville, and the Custom House in Chattanooga are built. The St. Clair marble would make a fine trimming for brick or stone buildings, especially buildings of darker colored stone. It would make a good monumental stone, and would be desirable for interior decoration where a light soft color is wanted. On account of the massive form in which it occurs, pillars and columns of any desired size could be obtained, and its rich but modest coloring and its brilliant polish add to its desirability for these uses. The deeper colored varieties such as that on North Sylamore would be valuable for cabinet work and interior decoration. It is well suited for tiling and wainscoting.

CHAPTER XVII.

The Distribution of the St. Clair Marble.

NORTH SIDE OF WHITE RIVER.

The St. Clair marble outcrops over a somewhat irregular belt eighty miles or more in length and from two to ten miles in width, running across the central part of North Arkansas in a nearly east and west direction, and extending from Hickory Valley in range 5 W. to Mt. Hersey in range 19 W., with isolated outcrops as far west as Jasper, in range 21 W. In Independence county, at the eastern end of the area, the outcrop is all on the north side of White River; it crosses White River at Penter's Bluff, from which place it occurs on both sides of the river as far west as Round Bottom, west of which it appears only on the south side of the river. Its northwestern boundary in the main is the fault near St. Joe.*

In the western part of its area the bed is comparatively thin; its maximum thickness is exposed at Penter's Bluff. The western and northwestern limits of the bed are fairly well defined. On the south it dips beneath the overlying Lower Carboniferous beds of the Boston Mountains.

(The Batesville map sheet.†)

The Batesville map sheet shows the marble area of Independence county, and small parts of that of Stone and Izard counties, or the eastern part of the marble area, from the eastern border to range line 8 W. Inasmuch as the marble outcrop forms an escarpment along the streams, the descriptions of the details of its distribution will follow the drainage of the country in which it occurs.

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*See chapter on Faults.

†The map of the Batesville region on which the distribution of the marble is shown is slightly modified from that accompanying Vol. I., of the Annual Report of this Survey for 1890.

The Polk Bayou basin.*—Except the traces of marble which occur on Dota Creek, the most eastern tributary of White River on which marble occurs is Polk Bayou, which joins the river at Batesville. The southernmost exposure of the marble in the valley of Polk Bayou is two miles north of Batesville, where it occurs at the water's edge; to the north it outcrops along the hillsides rising up-stream (northward) for five miles, where it reaches the tops of the hills and is cut off by erosion. In many places it has entirely disappeared, while both the underlying and overlying rocks remain. Whether the disappearance of the bed at intermediate points is due to the more rapid decay of the St. Clair marble or to the original thinning of the bed it is not possible to say. The general south dip of the rocks is well shown by the marble outcrop, which disappears at the top of the hill at its north limit and at the base of the hill at the south limit; however, its sudden disappearance at the south limit on Polk Bayou is partly due to a fault which has its downthrow on the south side.†

At *St. Clair springs*, in 14 N., 6 W., section 24, on Miller's Creek, the lowest tributary of Polk Bayou on the east, is an outcrop of marble, which is the most eastern exposure in the state, and the one from which the marble is named. East of the Batesville-Evening Shade road the marble occurs on the hill for more than half a mile above the springs, and also in one small exposure west of the road in 14 N., 5 W., section 18, the northwest quarter. For nearly a mile below the springs the rock outcrops in low bluffs on the east side of the stream, but it is not exposed at all west of it. At the St. Clair springs the rock is fossiliferous, and is exposed in large boulders and crumbling ledges which have a loose, shelly surface. About half a mile down-stream from the springs on the east side of the creek is a cave at the base of the cliff, and in the mouth

*The term *bayou* as applied to this creek is unfortunate and misleading; the stream is not a sluggish one with much standing water, as one would expect from the name, but a rapid, clear water stream. Rocky Bayou in Izard county and Little Rocky Bayou in Stone county are also clear mountain brooks.

†See Vol. I., of the Annual Report for 1890, p. 111.

of this cave the marble is solid and crystalline; while the limestone overlying it is but slightly crystalline and of a bluish gray color. So far as shown by surface indications, but little rock of commercial value could be obtained at this exposure, unless it be for lime burning. However, underneath the surface, the rock may be more uniform and crystalline in texture.

Southwest of St. Clair Springs, in 14 N., 6 W., section 34, north of Mr. Meacham's house, is an exposure of the St. Clair marble, which is partly concealed by chert debris. There is also a small exposure of the underlying Izard limestone, which is the most southern exposure of that rock in the state. West of Mr. Meacham's, on the Cason place, in the same section, is a larger outcrop of the marble, with a thickness of more than 100 feet, nearly all of which is exposed, the bottom being concealed. The marble on the hill immediately north of the manganese diggings at the Cason place, lies in admirable position for quarrying. The slope is covered with large rounded boulders and ledges, which for the most part are disintegrated to the depth of an inch or more, yet some heavy ledges occur in which the marble is fairly sound on the surface. The rock is fossiliferous throughout the bed, numerous fragments of fossil trilobites occurring with brachiopods, bryozoans, etc. The part of the marble bed above the manganese, Dr. H. S. Williams classes from paleontologic evidence as the equivalent of the Niagara, and the bottom of the bed in which the manganese occurs, as Trenton.

Between the Cason place and Polk Bayou the marble is largely concealed beneath the fragmentary chert.

On Polk Bayou the marble outcrops in 13 N., 6 W., sections 4 and 5, at the first crossing of the wagon road up the bayou from Batesville. A short distance below the ford the marble disappears—carried below the drainage level, partly by its south dip and partly by a fault with the downthrow on the south side. On the east side of the bayou, above the ford, the outcrop of marble is nearly 100 feet thick, with color varying from pinkish gray to brownish red; the bottom layers exposed are fossiliferous.

In 14 N., 6 W., sections 32, 33, and 28, along a small tributary on the east side of the bayou, a pinkish gray, highly crystalline marble occurs in large weathered boulders and heavy ledges; at the mouth of the ravine the outcrop is concealed on the west side by the broken chert, but it outcrops on the east or south side; towards the head of the ravine it is exposed in weathered ledges on the slopes, and it occurs in the manganese mines in rounded irregular boulders of compact highly crystalline rock.

From the mouth of this ravine to the mouth of Cave Creek, near the middle of section 29, a distance of a mile and a half, the marble occurs in a continuous bed on both sides of the bayou concealed in places by the chert debris; it varies in color from a grayish pink to a brownish and purplish red. It commonly outcrops in huge boulders and rounded ledges from two to five feet in thickness, but in a few places it exfoliates in slabs or layers, which split off along planes parallel with the slope of the hill and regardless of the bedding of the rock. The exfoliation is prominently marked in 14 N., 6 W., section 32, on the east bank of the bayou at the fourth ford above Batesville. The marble is here stained to a deep reddish brown with manganese, and interspersed with fossil casts of white calcite. The marble is overlain by the Boone chert, which forms a perpendicular bluff at this point sixty feet or more in height. (See Plate XI.)

Less than a quarter of a mile above the mouth of Cave Creek is a small bifurcated tributary entering Polk Bayou from the west; on the left or southern branch of this stream but little marble is exposed, while on the tributary from the northwest there is a large exposure, overlying the Izard limestone, which occurs along this creek and the base of the hills as far as the spring in 14 N., 6 W., section 30, the southeast quarter of the northeast quarter. The overlying St. Clair marble is exposed on the hills on both sides of the creek as far as the manganese openings in section 30, in the northwest quarter of the northeast quarter. A section at the spring above referred to shows twenty feet of Izard limestone at the bottom of the

hill overlain by eighty feet of marble exposed, and possibly more concealed, as the contact with the chert was not found, and measurements on the bayou hills, both above and below, show a thickness greater than this. Much of the marble exposed in the ravine is of fine quality.

On the east side of Polk Bayou above the mouth of Cave Creek the marble outcrops at intervals through the broken chert for a mile or more. On the hillside west of the bayou the outcrop is more conspicuous; in 14 N., 6 W., section 29, the northwest quarter, it is nearly 100 feet in thickness, with 50 feet of chert overlying it. A little more than half a mile to the northwest, in section 19, the southeast quarter of the northeast quarter, the marble is concealed by the chert, and north from this point on the west side of Polk Bayou at the manganese openings only a few isolated exposures mark the marble horizon. Among those noted are the ones at the manganese diggings on the hilltops in the western part of section 18; small exposures on Prairie Creek in 14 N., 7 W., sections 23, 24, 14, 10, 9, 4, and 3; and in 15 N., 7 W., section 35.

Cave Creek derives its name from the numerous caves found along its banks, the first of which, known as Bell Cave, is in the Izard limestone at the base of a hill in 14 N., 6 W., section 29, the southeast quarter, while all the others up-stream from this point are in the St. Clair marble or the limestone of the Boone chert; the most noted of these caves is the Saltpeter Cave in 14 N., 6 W., section 14, the northwest corner, where saltpeter was made during the civil war.

For a distance of a mile and a half up the creek from Bell Cave no marble is exposed, as it is concealed by the chert debris. Just above the old gin near the middle of section 21 the marble reappears, and continues exposed along the southeast side of the creek for more than two miles, and to the middle of section 14, and at intervals above this in the northeast quarter of section 14, the northwest quarter of section 13, and the southwest quarter of section 12. Through the northern part of section 22 and the southeast quarter of

section 15, the Izard limestone outcrops along the base of the hill and in the creek bed. The hills on the north side of Cave Creek are covered with the broken chert and no marble outcrop was observed, but it is exposed in small ravines half a mile and more from the creek. There is a large exposure of St. Clair marble about the Trent mine and the Saltpeter Cave in 14 N., 6 W., sections 10, 11, and 14. Along the east hillside north of the cave, in the southwest quarter of section 11, it is fossiliferous and much weathered. Much of the marble along Cave Creek has little if any value as a building or ornamental stone, as it is not completely marmorized and weathers with a lumpy crumbling surface, showing lack of firmness, strength, and homogeneity. The most promising outcrop observed is at Mr. Bales', in section 14, where it is quite crystalline and compact, and where many of the citizens obtain stone to line their fireplaces, as it is said to withstand the heat remarkably well.

At the O'Flinn manganese mine in 14 N., 6 W., section 22, the marble is 120 feet or more in thickness. The lower half of the bed contains some nodular chert and weathers irregularly. The upper half of the bed, or the part above the manganese, is more uniform in texture, brighter in color, and promises a much more valuable marble. It lies favorable for quarrying, forming as it does the top of the hill. The marble contains fossil fragments throughout the entire thickness of the bed, one layer about four feet in thickness near the middle of the bed being very fossiliferous; the predominating species is *Rhynchonella capax*, this species alone forming a large part of the rock. Paleontologic evidence shows the upper part of the bed to be Niagara, and the lower part, below and including the *Rhynconella* bed, to be Trenton.

It is possible that good marble occurs at other places along Cave Creek beneath the inferior surface rock, but the possibility of opening at any time into one of the numerous caverns would make the quarrying of it for dimension stone alone attended with considerable risk.

*Coon Creek and Hickory Valley.**—As the marble on the headwaters of Cave Creek disappears beneath the overlying rocks one would expect, under ordinary conditions, to find it outcropping on the north side of the watershed; but it does so in only a few places. Thus in the middle of section 10, northwest of the Trent mine on the hill at the head of Hunt Hollow, a branch of Coon Creek, is an outcrop of St. Clair marble from twenty to thirty feet in thickness, while on the hill south of the public road in the northern part of section 1, the marble is simply an incrustation, about a quarter of an inch thick, on the blue Izard limestone. In 14 N., 5 W., section 6, on Mr. Chinn's place, and at Mr. Milligan's in the same section, the bed reaches a thickness of about fifty feet. A small boulder of the marble was seen east of Mr. Robt. Meacham's at Hickory Valley, in section 5, and larger pieces are reported to have been taken away, but no considerable quantity of it is there exposed. No outcrop of marble was observed east of those near Hickory Valley, although it is possible that traces of it may occur along the south and west side of Dota Creek. The small quantity of marble outcropping along the northern exposure is due in part to its leaching away, and its reduction to residuary soils, and in part to the thinning out of the marble bed.

Spring Creek.—Spring Creek, which empties into White River at Batesville half a mile above the mouth of Polk Bayou, heads at the Big Spring in 14 N., 7 W., section 27, though it drains an area of several square miles northwest of the spring. The St. Clair marble outcrops on the axis of a low anticline on the hill on each side of the water-tank, two or three hundred yards south of the spring. The entire thickness of the exposure is not more than forty feet, and the length of the outcrop possibly not more than 100 yards. The color varies in different layers from light gray to red. There are many fossil casts of white crystallized calcite, which in the dark red body give the rock a variegated and pleasing appearance. The crystal-

*The Hickory Valley on the map is what is known locally as Hickory Valley, but in 1889 the post-office of that name was one mile further south.

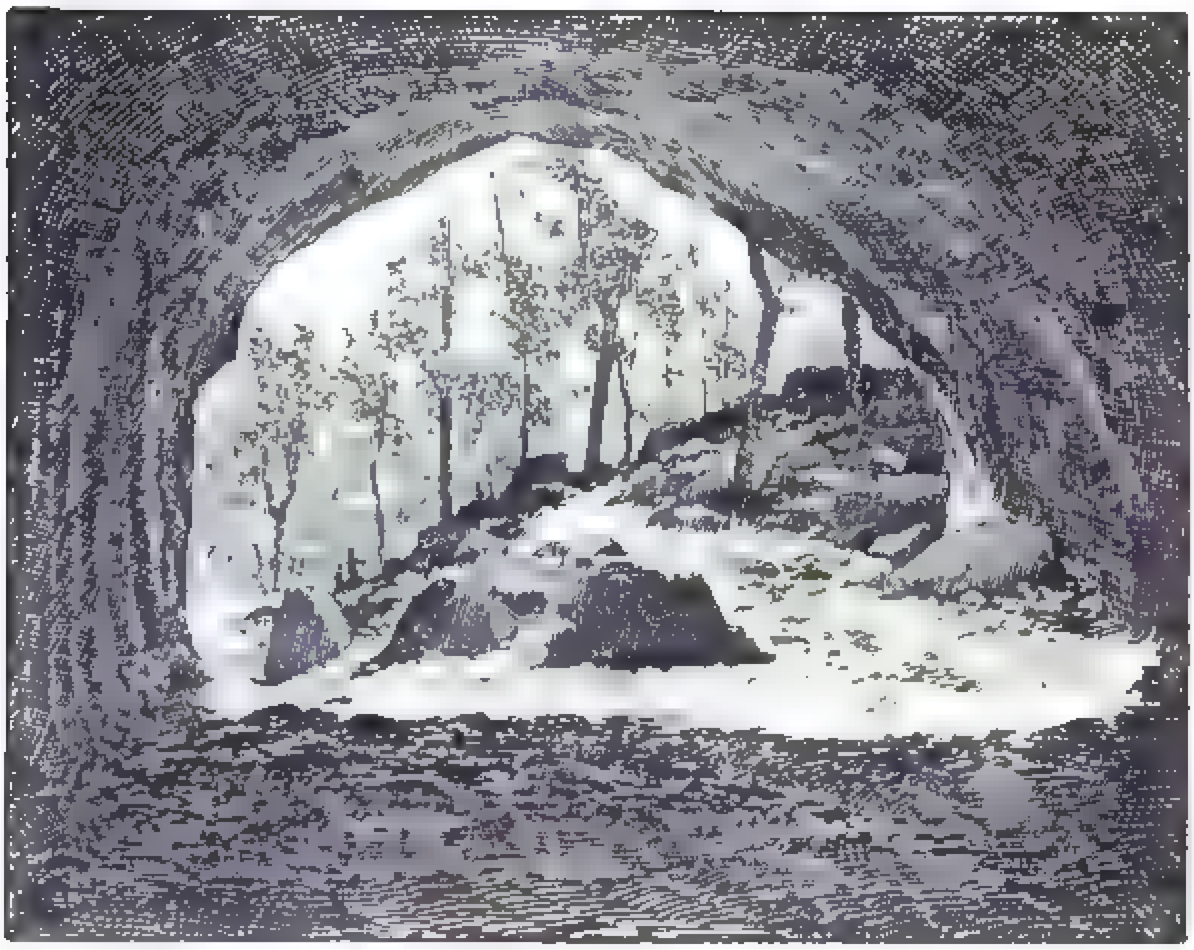
line marble is overlain by a bed of amorphous blue limestone which would make a good lime. So far as indicated by surface exposure, the rock west of the railway promises a finer quality of marble than that on the east.

The Sylamore sandstone, which immediately overlies the Silurian, was not observed in contact with the St. Clair marble, but loose boulders of it occur on the hill east of the railway and a continuous ledge of it west of the railway, a few yards south of the marble exposure, at or a little below the same level as the marble, thus showing that the marble dips rapidly to the south.

This is the nearest exposure of the St. Clair marble to railway transportation, being not over 100 yards from the Cushman extension of the St. Louis, Iron Mountain & Southern Railway.

East Lafferty Creek.—Lafferty Creek is a large ramifying tributary of White River which enters the latter stream about 20 miles above Batesville; the mouth of the creek is in 14 N., 8 W., section 16, the southeast quarter of the southeast quarter. Two exposures of St. Clair marble occur on a small tributary of this creek from the east in sections 14 and 13 (14 N., 8 W.). The first of these exposures as one ascends the creek is in section 14, the southeast quarter, and section 13, the southwest quarter; it outcrops on the hillsides a short distance above Mr. Pitman's house, and is exposed on both sides of the ravine for a distance of more than half a mile. A section in one place shows three or four feet of blue Izard limestone at the base of the hill, overlain by 80 feet of St. Clair marble, above which are from 10 to 30 feet of broken chert. In the southern part of section 13 is a small syncline where the marble in the southwest quarter of the section dips east beneath the surface a .d reappears in the southeast quarter, where it is exposed for a distance of 200 yards and is again concealed beneath the chert. In both these exposures the marble lies in good position for quarrying. and, so far as can be judged from the weathered exposure, the stone is of good quality.

At the confluence of East Lafferty and West Lafferty



FARRELL'S OR BLOWING CAVE.

Creeks, a little more than a mile from the mouth of the stream, the end of the hill between the two creeks is almost entirely composed of highly crystalline, firm, solid marble, which weathers in heavy ledges and rounded boulders; although partly covered with broken chert, this is a larger and more conspicuous exposure than has been observed elsewhere.

On the north and west side of East Lafferty Creek the marble outcrops along the face of the bluff or steep hillside through the north part of section 14, and the south and east part of section 11 (14 N., 8 W.), where it is underlain by a heavy bed of Izard limestone and covered with a heavy bed of chert. Through the northeast quarter of section 11 and the east part of section 2, the marble outcrops only in spots near the top of the hill, while the chert debris in most places rests directly on the Izard limestone. On the south and east side of East Lafferty Creek, especially along its tributaries, large quantities of marble are exposed. On both sides of the crossing of the Pine Hollow road, in the north part of section 14, the marble outcrops in a low bluff at the level of the stream; it has a marked southwest dip at this place, so that on the north and east it rises higher on the hillsides. It outcrops in heavy ledges along both sides of the small tributary which enters from the east, in the north part of sections 13 and 14, and in the south part of section 12, extending into 14 N., 7 W., section 18, the northwest quarter.

Blowing Cave Creek, named from the big cave (Farrell's or Blowing Cave) in 14 N., 7 W., section 8, is an affluent of East Lafferty Creek from the east in 14 N., 8 W., section 12, the northeast quarter, which with its two branches drains parts of sections 4, 5, 6, 7, and 8 (14 N., 7 W.). On the south branch of the creek which heads in section 8, half a mile west of Cushman, is a large exposure of St. Clair marble. It outcrops about the head of the creek at the manganese openings on the Meeker place, in large rounded boulders, and through section 7 (14 N., 7 W.) it shows in heavy ledges.

A section of the hill on the north side of the creek opposite Blowing Cave shows the following succession of the rocks:

Section on Blowing Cave Creek.

Fragmentary chert	Surface.
Sylamore sandstone	40 feet.
St. Clair marble	90 feet.
Izard limestone, bottom concealed	140 feet.

The lower part of the marble bed is coarsely crystalline and outcrops in heavy ledges. The upper part is deeper colored, shelly and fossiliferous. The marble outcrops on the south side of the creek on the hill above the cave and at intervals along the hill westward to East Lafferty Creek. The outcrops along this creek indicate a marble of fairly good quality.

The Sylamore sandstone at the Meeker place is very shaly and varies from two to ten feet in thickness. In the bottom of the bed, or between the sandstone and the marble, is a bed two or three feet thick of a shaly iron ore. Opposite the Blowing Cave the sandstone occurs in heavy layers three to four feet thick.

The St. Clair marble outcrops at Phelps' Spring, half a mile north of Cushman, at the head of the north branch of Blowing Cave Creek. It is found in the manganese openings and, as occasional weathered boulders and ledges, in the chert debris on the hills about the spring and westward. No exposure of the marble has been found north of the north branch of Blowing Cave Creek, but a more detailed examination might discover small areas about the borders of the Boone chert islands between this stream and Barren Fork.

West Lafferty Creek.—On West Lafferty Creek some fine and extensive marble outcrops occur on the hills on each side of the main stream and in the numerous ravines which drain into it. In a short ravine which joins the principal stream in 14 N., 8 W., section 10, the southeast corner, and which extends in a northeast direction to near the middle of section 11, there is a large exposure of St. Clair marble of fine quality. Another ravine, known locally as Hankin Hollow, enters West Lafferty Creek from the northeast near the middle of section 10. In the St. Clair marble near the head of this hollow is a large cave, both above and below which the marble is exposed in

heavy ledges; it outcrops in huge boulders about the manganese openings and on a secondary branch from the east a short distance below the cave.

Above the mouth of Hankin Hollow the marble outcrop extends nearly two miles up the east side of West Lafferty Creek, with an average thickness of sixty feet or more. At the lithographic quarry, in 14 N., 8 W., section 10, the marble is about sixty feet thick. In 15 N., 8 W., section 35, near the north limit of the marble, a section shows:

Section on West Lafferty Creek.

Boone chert	240 feet.
St. Clair marble	60 "
Izard limestone	120 "
Saccharoidal sandstone	at base.

The contact between the chert and marble was not found, so that the marble may be more than sixty feet thick.

The marble exposures on the west side of West Lafferty Creek are larger than those on the east side; the outcrops are especially prominent in the numerous small ravines in 14 N., 8 W., sections 3 and 4, and in 15 N., 8 W., section 34, where it is 100 feet thick. The northern limit of marble on West Lafferty is on the south side of the Ruminer Hollow, in 15 N., 8 W., sections 33 and 34, where, as in other places along the northern border, the outcrop is not continuous, being concealed by the chert debris in many places and absent in others. It is possible that there are small exposures of marble north of Ruminer Hollow, but none have been seen.

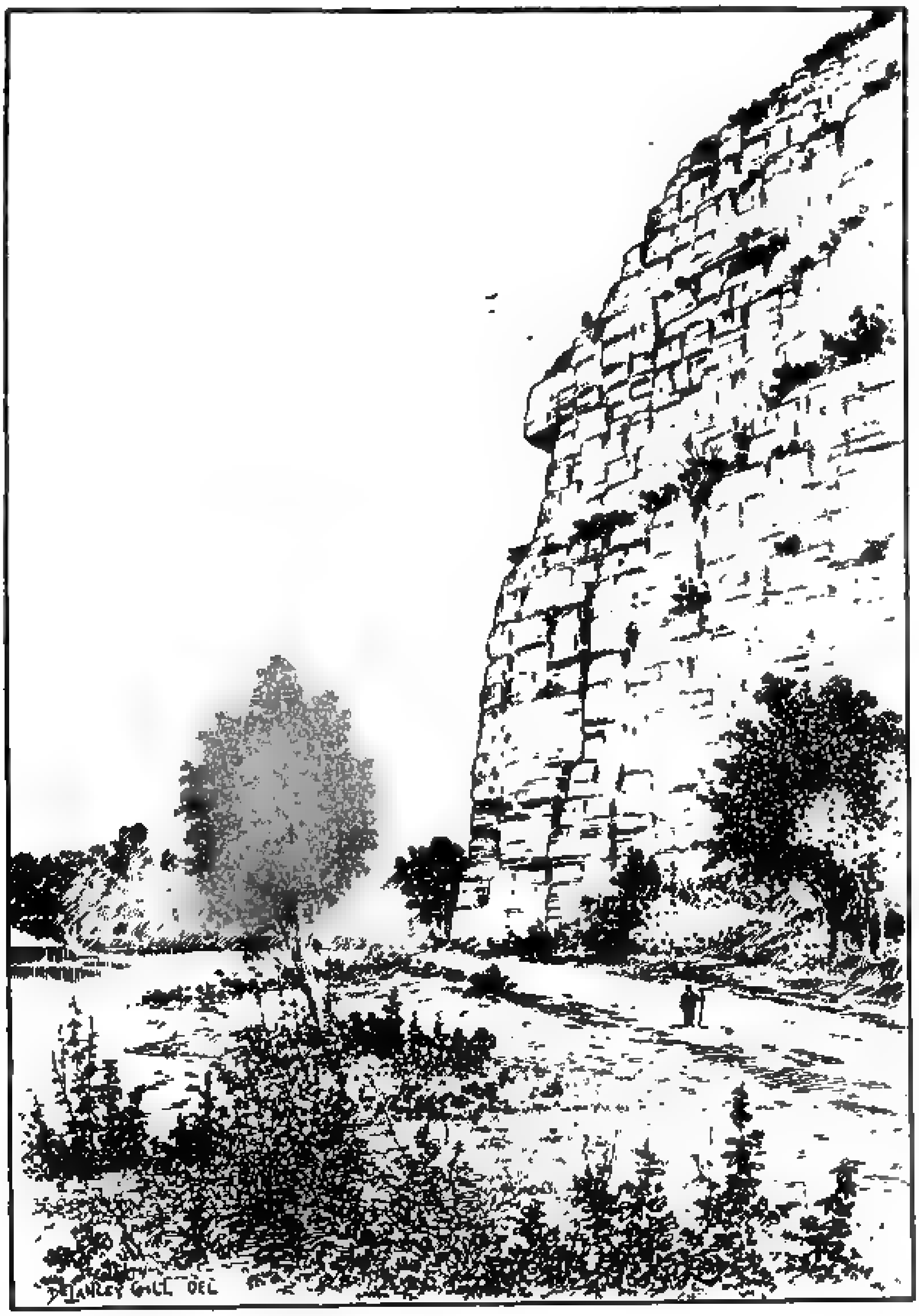
Penter's Bluff.—At Penter's Bluff on the northeast bank of White River, one mile above the mouth of Lafferty Creek, in 14 N., 8 W., section 9, is the heaviest body of limestone exposed in the state. The total height of the bluff is 435 feet, but on top of this is 50 feet of Boone chert sloping back from the face of the escarpment. This bold face, in most places perpendicular, but with a few narrow projecting ledges and dotted here and there with red cedars, extends along the river for a distance of a mile and a half. Of the 435 feet of the cliff's sheer face, 155 feet at the top are St. Clair marble, and

280 feet at the base are Izard limestone, which extends to the water's edge; the base of the limestone is concealed so that its total thickness is not shown, but is probably not much greater than that shown in the exposure. The parting between the limestone and the overlying marble is not clearly defined; between the solid crystalline marble and the compact, smooth-grained limestone is a lumpy, crumbling, slightly crystalline limestone, whose thickness is included in the 280 feet of Izard limestone in the section above. Overlying the somewhat irregular upper surface of the marble is a layer of impure sandy, shaly material, above which is the stratigraphical representative of the St. Joe marble, consisting of 10 to 12 feet of gray, slightly crystalline limestone.

At the upper end of the bluff a short ravine enters the river at right angles; at the lower end another ravine bends around behind the bluff and extends parallel with it nearly to its upper end. The bluff is thus a high wall between the river and the deep gorge behind it, and is connected at the upper end with the watershed between White River and Lafferty Creek. The upstream end of the escarpment drops off very abruptly at the upper end; at the down-stream end it is yet quite steep. At the rear of the bluff on the side next to the gorge the steep slope rises in benches or terraces from 2 to 6 feet high, according to the thickness of the different layers. The lower end of the bluff for 200 yards or more is composed entirely of the Izard limestone; the marble forms the top rock for possibly the same distance, and the chert, which forms a heavy bed back from the upper end, does not extend much below the middle of the bluff. (See Plate XIII., also page 113.)

The natural advantages of this locality for quarrying either for lime burning, or for dimension stone, or for both, are unusually good, as in addition to its favorable exposure the ridge above the bluff contains an almost unlimited amount of wood for lime burning, while at the base flows White River, navigable from this point down-stream at nearly all seasons of the year.

The marble extends not more than half a mile below the bluff where it descends below the water-level.



PENTER'S BLUFF ON WHITE RIVER.

On the north side of the river above Penter's Bluff a strip of alluvium varying from a hundred yards to half a mile in width, lies between the river and the hills and continues up the river for several miles. Nearly half a mile up-stream from Penter's Bluff the public road from the river to West Lafferty Creek ascends a short ravine which opens into the river valley from the north; on both sides of this ravine the marble and blue limestone outcrop, the largest exposure being on the west side, where the hill near the mouth is 430 feet high and the marble near the top is from 100 to 130 feet thick, covered in places with fragments of chert. The marble near the head of this ravine outcrops in rounded fossiliferous masses and ledges.

Lafferty Hollow.—Lafferty Hollow is a little more than a mile west of Penter's Bluff. On the hill on the east side near the mouth of the hollow, between the main hollow and a small ravine from the northeast, is a fine exposure of marble 150 feet thick capping the hill for a distance of over 300 yards with no overlying chert. This locality offers splendid facilities for quarrying. While the marble is exposed in large quantities on each side of Lafferty Hollow near the river, it is mostly concealed about the upper end of the ravine, where the valley is wider than at the mouth, and the low sloping hills are covered with broken chert, with an occasional marble ledge protruding. The largest outcrop in the upper part of Lafferty Hollow valley is in 15 N., 8 W., section 29, the southeast quarter, at and below the cave near Mr. Blassingham's house.

The maximum thickness of the St. Clair marble appears to be at Penter's Bluff and the contiguous region, where the erosion of numerous deep ravines has exposed it in large quantities, so that there is probably more marble exposed to view in 14 N., 8 W., sections 3, 4, 5, 9, 10, 11, 14, and 15 than on any equal area in the state.

Wilson Creek.—The largest tributary of White River from the north between Lafferty Creek and Rocky Bayou is Wilson Creek, which is a little more than four miles in length. Both on the main creek and its numerous affluents the marble is exposed in large quantities. The largest outcrop observed is on

the branch from the northwest in 15 N., 8 W., section 30, where it is exposed in weathered ledges with an apparent thickness of more than 150 feet. On a small secondary branch from the west, in section 30, northwest corner, and section 26 (15 N., 9 W.), northeast corner, some fine solid ledges are noticeable on the hills about Mr. Coleman's house.

Wilson Creek flows through a deep, narrow, rocky gorge; the slopes of the bordering hills, from 400 to 500 feet in height, are covered with heavy ledges of Izard limestone and St. Clair marble and are capped with the Boone chert. Both the marble and limestone are of fine quality.

(The Mountain View map sheet.)

Campbell Branch.—On Campbell Branch, the small tributary of White River in 15 N., 9 W., section 36, the rock exposures are similar to those on Wilson Creek, except that the hills are not so rugged and steep. Up-stream from Mr. Campbell's house the marble is mostly concealed by the chert debris, but down-stream the marble and Izard limestone are exposed in large quantities, the marble in one place measuring 100 feet in thickness. Just below the mouth of the creek on the river hill is a bold, almost perpendicular outcrop of the Izard limestone and marble which have a slight dip to the southeast.

Cedar Branch.—On Cedar Branch but little marble is visible —not that it does not exist, but because its horizon is in large part concealed by a fragmentary chert.

Rocky Bayou.—On Rocky Bayou traces of the marble occur on or near the tops of the hills for a mile or more up the creek from the river. In 15 N., 9 W., section 14, the southwest quarter, the bluff on the east side of the creek consists of 170 feet of saccharoidal sandstone overlain by 150 feet of the Izard limestone. The chert occurs a short distance back from the creek, but no marble was observed. A short distance downstream from the bluff above mentioned, on the west side of the creek, is an outcrop of crumbling marble 40 feet thick; traces of marble possibly occur further north, but only as small patches on the tops of the highest hills.

Hidden Creek.—On Hidden Creek an inconspicuous outcrop of weathered marble along the hillsides extends back (north) from the river for a mile; in section 22 (15 N., 9 W.), the southeast quarter, it measures twenty feet in thickness. A section on the river bluff west of the mouth of this creek exposes 280 feet of Izard limestone and saccharoidal sandstone overlain by fifty feet of St. Clair marble, with thirty feet of Boone chert above it.*

North side of White River above Hidden Creek.—No marble worth mentioning was found on Rock Castle Creek and Lyon's Creek, the next tributaries flowing into White River above Hidden Creek. There are some inconspicuous outcrops in sections 17, 18, and 19 (15 N., 9 W.). There is a long high bluff on the north side of the river below Round Bottom, in 15 N., 10 W., sections 23 and 26, similar in general appearance to Penter's Bluff and the Hidden Creek Bluff, but differing from them in having a heavy bed of saccharoidal sandstone at the base and only a mere trace of marble near the top, a few scattered boulders only occurring in the chert debris. The blue Izard limestone in this bluff is of very fine quality, weathering out in firm rectangular blocks.

It is reported that there are traces of the St. Clair marble in 15 N., 10 W., section 13, the southwest quarter; it is possible that these small exposures are at the northern limit of the outcrop. It is highly improbable that there is any considerable quantity of St. Clair marble on the north side of the river above Round Bottom; whatever remnants of the bed may occur there are not likely to have any commercial importance or an areal distribution which would give it geologic importance. For these reasons no detailed examination was made of the St. Clair marble on the north side of the river above Round Bottom.

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*For illustration, see Plate IV.

CHAPTER XVIII.

The Distribution of the St. Clair Marble—*Concluded.*

SOUTH SIDE OF WHITE RIVER.

(The Mountain View map sheet.)

On the south side of White River, as on the north side, the marble outcrops along the narrow winding watercourses. On both sides of the river the rocks have a gentle south dip, so that as the northern limit of the bed is approached the marble bed occurs higher and higher up the hillsides until it is finally displaced by the underlying Silurian rocks. On the south side of the river the marble gradually descends to the beds of the streams, where it dips away gently toward the south, disappearing beneath the overlying Lower Carboniferous rocks. Except where concealed by the chert debris, the marble outcrop on the south side of the river is continuous as far west at least as range 12.

The eastern limit of the marble outcrop on the south side of White River is in 14 N., 8 W., section 5, the northwest quarter, just above Penter's Bluff. Opposite the bluff the marble horizon is concealed by chert debris; up-stream from the outcrop in section 5, the hills become steeper and are closer to the river—so close that they form a river bluff from Penter's Bluff to the mouth of Sylamore Creek, broken by numerous small creeks and ravines and by two short strips of alluvium, viz.: Jones Bottom, in range 9 W., and Round Bottom, in range 10 W. This bluff is not so high nor so prominent as Penter's Bluff, but it consists of the same rocks—Izard limestone at the base, overlain by St. Clair marble, which is capped with chert. A small exposure of the underlying saccharoidal sandstone occurs in section 21 (15 N., 9 W.), and from a short distance below Round Bottom the same rock is exposed along the bluff up to Sylamore Creek.

Cagen Creek.—Cagen Creek, like most of the streams on the south side of White River, heads in the Boston Mountains, well up in the Lower Carboniferous rocks, through which it cuts channels which gradually deepen towards the river, its lower course being in the Lower Silurian rocks. The marble in the hills on each side of the mouth of Cagen Creek extends from near White River to Mr. J. Greenway's house, in 14 N., 9 W., section 3, near the middle of the section. The blue Izard limestone extends up almost to the township line on the north side of section 3. The bottom layers of the marble are of inferior quality, being lumpy, full of seams, and but partly crystalline. The upper layers are very firm and massive, in one place there being a clear exposure of twenty feet, apparently without seam or flaw, and with both the top and the bottom of the bed concealed. The measurements made of the thickness of the marble bed on Cagen Creek are as follows: one on the west side of the creek in the south part of section 34 (15 N., 9 W.), where it is eighty feet thick; one on the east side of the creek in the east side of section 34, where it is ninety feet thick; and one on the west side of the creek near the mouth, in section 35, where it is 100 feet thick. The contact of the marble with the overlying rocks could not always be determined, so that these measurements are really less than the thickness of the marble bed.

On the north side of section 3 (14 N., 9 W.), on the north side of a sharp bend in the creek, is a cave-like opening in the St. Clair marble at the base of the hill, which is said to extend through the hill half a mile to an opening on the south side, and through which the water flows during freshets.

*Dry Creek.**—The marble exposure on Dry Creek is similar to that on Cagen Creek, and extends about the same distance up the stream, the upper limit being in 15 N., 9 W., section 32,

*Dry Creek owes its name to the fact that, except in a few places, its stream flows beneath a bed of chert gravel. It is unfortunate and perplexing that this name, like Mill Creek, Bear Creek, Cave Creek, etc., should be given to so many streams; there are not less than three Dry Creeks in Stone county less than fifteen miles apart, to say nothing of the numerous ones in the counties further west.

the northern part. On the north side of the creek, near the river, the marble is over 100 feet in thickness and quite massive. In section 33, the middle of the north half, is an exposure of thirty feet of the Izard limestone at the bottom of the hill, overlain by 100 feet of marble, the adjoining layers of the blue limestone and the marble, as on Cagen Creek, being crumbly and loose-textured; but the larger part of the marble occurs in massive ledges. It varies in color from pinkish gray to dark red, and in a few places exfoliates like the manganiferous variety on Polk Bayou. There is a superior quality of the blue Izard limestone near the mouth of Dry Creek. More than half a mile above the mouth of Dry Creek the hills retreat some distance from White River, leaving a narrow belt of river bottom, which continues up-stream to the mouth of Rocky Bayou in 15 N., 9 W., section 18, the southwest quarter. Along these hills the Izard limestone is near the hilltops, and but little marble is exposed. Several small ravines score the face of this hill, one of which in section 21 (15 N., 9 W.), the northeast quarter, near Mr. Lancaster's, contains large quantities of blue Izard limestone of fine quality, with eight or ten feet of weathered marble exposed near the top of the hill; in another place in section 17 (15 N., 9 W.), the east part of the section, at Jones' Ferry, the Izard limestone extends almost to the top of the hill and a few scattered boulders of marble appear in the chert debris, but it was not observed in place. South of the gin in section 18, the northeast quarter, is an exposure of forty feet of marble, underlain by a fine quality of Izard limestone; the outcrop of both is nearly continuous to the mouth of Little Rocky Bayou.

Little Rocky Bayou.—Just above the mouth of Little Rocky Bayou there is a high narrow, rocky ridge over two miles in length, lying between the creek and the river. On the river side it is a perpendicular bluff, while on the creek side it is perpendicular in places, and steep all the way. Two or three local flexures, more prominent on the river side, occur in the rocks of this ridge, in which the dip is from 4° to 15°. In two places on the side next the creek the marble is forty and

forty-five feet in thickness, while in other places it is all concealed. In many places up the bayou the marble is concealed by the chert fragments, and the measurements given represent only the exposures and not the entire thicknesses of the bed, for in no place was the contact with the overlying rocks seen.

At Mr. Williams' house, at the head of the ravine in 15 N., 10 W., section 22, is an exposure of disintegrated St. Clair marble from 20 to 25 feet thick. In a small lateral ravine in the southeast quarter of the same section the marble has an exposure 45 feet thick and the quality is much better, the surface being firmer and the texture more homogeneous. The underlying Izard limestone is of better quality here than was observed elsewhere along Little Rocky Bayou. In another small ravine on the southwest side in section 27, the northeast quarter, the marble is 85 feet thick. West of Mr. Nesbitt's sawmill, on section 26 (15 N., 10 W.), the southeast quarter of the northeast quarter, is an exposure of saccharoidal sandstone at the base of the hill; above this is an outcrop of 150 feet of Izard limestone, the bottom layers of which are siliceous; overlying the limestone is an exposure of St. Clair marble 20 feet thick, and above that the chert debris. In the branch ravine from the west above the mill, marble of inferior quality is exposed for nearly two miles from the creek. All the marble, so far as observed, on Little Rocky Bayou above Nesbitt's mill, is of poor quality for purposes other than lime burning, being full of seams, uneven of texture and but partly crystalline; however, there may be local occurrences of marble of good quality, as the examination of this area by the Survey was a hasty one.

There are some small exposures of marble in the small ravine in section 22 (15 N., 10 W.), the northeast quarter, in the hills along White River. South of Round Bottom in sections 15, 16, and 21 (15 N., 10 W.), the marble is concealed by chert debris.

Hell Creek.—Hell Creek heads east of Mountain View and runs nearly due north. The lower course of this stream is through a deep narrow channel cut in a heavy bed of saccha-

roidal sandstone, which is exposed from a short distance south of the mill to White River. South of the southern limit of the saccharoidal sandstone the creek cuts through the Boone chert, the St. Clair marble, and the Izard limestone. The marble, which is from 50 to 80 feet in thickness, is of an even texture, varies in color from pinkish gray to red, and is a comparatively pure carbonate of lime, as shown by the following analysis:

Analysis of St. Clair marble from Hell Creek.

	Per cent.
Lime (CaO)	55.74
Magnesia (MgO)	slight trace.
Ferric oxide (Fe_2O_3)	.30
Alumina (Al_2O_3)	.10
Silica (SiO_2)	.32
Phosphoric acid (PO_4)	.49
Potash (K_2O)	.17
Soda (Na_2O)	.22
Loss on ignition (carbon dioxide and volatile matter)	43.31
Total	100.65
Water at 110°-115° C	.06
Calcium carbonate ($CaCO_3$)	98.49

The largest exposure on Hell Creek is in 15 N., 10 W., section 31, the northeast quarter, on the east side of the creek, where it forms the hill between two side ravines for a distance of 200 feet.

South Sylamore Creek.—South Sylamore Creek, with its tributaries, drains all the southern part of the Mountain View sheet in ranges 11 W., 12 W., and 13 W.; its general course is a little south of east; a few short tributaries enter it from the north, but more and longer ones from the south. The marble occurs along the creek to a short distance above its confluence with Roasting-ear, and also along Roasting-ear almost its entire length and along most of the north and south tributaries for a short but variable distance from the creek. On the Dry Creek tributary on the south side, the marble outcrop extends two miles south of the main stream, while on the Dry Creek on the north side it does not occur at all, nor does it outcrop on Lick Fork, the tributary from the south, and next west of Dry

Creek. A number of more or less gentle undulations occur in the rocks along the entire length of the creek, causing the marble in some places to outcrop in the creek bed, in other places a hundred feet or more above it. Both the quality and quantity of the marble vary in different parts of the valley. In 15 N., 11 W., on Dry Creek (south side), a considerable portion of the marble bed is amorphous and bituminous. In some places it is overlain by a heavy bed of sandstone and black shale, while in other places neither the sandstone nor the shale occurs.

On the west side of Dry Creek (south side of Sylamore Creek), in 15 N., 11 W., section 17, one exposure shows 70 feet of the St. Clair marble underlain by 110 feet of blue Izard limestone, and overlain by 80 feet or more of chert. The upper 20 feet of the marble is but slightly crystalline and is charged with bitumen. At the mouth of Dry Creek, in section 22 (15 N., 11 W.), the marble is more than 100 feet above the stream, but the rocks dip northwest, and the marble is carried down to the water-level in section 21. On the south side of Sylamore, opposite Mr. Prater's in section 21, the marble is from 75 to 80 feet thick; on the north side only a few feet of nearly amorphous limestone occur on the creek bank, while a few hundred yards west of Mr. Prater's, the marble horizon dips beneath the drainage level. In the south side of section 21 the marble occurs on each side of the creek, and from 50 to 100 feet above it.

There is a marked synclinal depression in the strata in the south part of section 16 (15 N., 11 W.), with a considerable exposure of Sylamore sandstone and Eureka shale, both of which formations are exposed in the creek bank at Mr. Prater's, also near the mouth of the ravine from the north, just east of Mr. Prater's house; the sandstone is exposed along the bottom of this ravine for nearly a mile from the creek. There is a heavy bed of the Sylamore sandstone exposed southeast from Mr. Prater's house, on the south side of the creek; also, in the southwest part of section 21 (15 N., 11 W.), on the north or

west side of the creek. The marble is not so crystalline where it is overlain by a heavy bed of the sandstone.

At the church on the south side of Sylamore Creek, on the west side of section 28 (15 N., 11 W.), is an exposure of 20 feet or more of St. Clair marble of fine quality. Overlying the St. Clair marble, from which it is separated by a bed of conglomerate, is a bed of St. Joe marble 10 feet or more in thickness, the bottom part of which is fine solid red marble.

Opposite the mouth of Lick Fork, on the north side of the creek is a fine exposure of St. Clair marble, underlain by the Izard limestone, the latter being fossiliferous, containing numerous fossil casts of *Orthoceras*, some of which are a foot or more in length.

Immediately above the mouth of Lick Fork, on the south side of Sylamore Creek, the St. Clair marble outcrops in heavy ledges with an exposed thickness of from 25 to 30 feet. On the north side of the creek at the junction of South Sylamore and Roasting-ear Creeks, the St. Clair marble is exposed near the base of the hill, and is overlain by a thin bed of greenish Eureka shale. The marble outcrops one mile or more up South Sylamore Creek, from its confluence with Roasting-ear Creek, into the north part of section 35 (15 N., 12 W.), where it disappears beneath the Lower Carboniferous rocks.

Roasting-ear Creek.—On Roasting-ear Creek the outcrop of marble extends nearly 10 miles above its junction with South Sylamore Creek. There is a large cave in the marble bed in 15 N., 12 W., section 25, the northwest quarter, just above which, in the short ravine from the north, the marble outcrops in a solid ledge along the base of the hill for nearly a mile, with a similar exposure in the next ravine to the west. The outcrop shows prominently in the large bluff on the outside of the horseshoe bend in section 23 (15 N., 12 W.), where it is 50 feet thick and apparently in a solid ledge without flaw or seam. On the sloping hillside at the upper end of this curve the marble has weathered in layers from 4 to 10 feet thick, the bottom layers being semi-crystalline and fragmentary, and the upper ones coarsely crystalline, homogeneous, and of a gray

color with a pink tinge. One mile up-stream from this bluff, on the hillside north of the creek, opposite the mouth of Panther Creek, is a solid ledge 40 feet thick of light pink colored St. Clair marble, which except a few surface seams, appears to be homogeneous and compact. It is overlain by 220 feet of Boone chert and limestone.

On the south side of Roasting-ear Creek and east of the mouth of Panther Creek, at Judge Cothran's, is a low point of land upon which many large boulders and ledges of highly crystalline St. Clair marble show through a light covering of soil. A section on the west side of Panther Creek, half a mile from its mouth and near the upper limit of the marble, shows 25 feet of marble at the base of the hill, 110 feet of chert with some intercalary limestone overlying, followed by 60 feet of limestone covered with 20 feet of chert.

There is a fine ledge of marble measuring 45 feet in thickness in the low bluff west of the mouth of Panther Creek on the south side of Roasting-ear Creek in section 27 (15 N., 12 W.). Up-stream from this exposure for several miles the creek is very winding and the marble, underlain by the Izard limestone, is exposed in the bluffs on the outside of the curves, while the sloping hillsides opposite the bluffs are generally covered with chert debris. In 15 N., 12 W., section 17, is a gentle anticline, on the axis of which a heavy outcrop of saccharoidal sandstone is exposed. This anticline begins in the southeast quarter of the section where the sandstone, which has a southeasterly dip of from 10° to 25°, occurs in the creek bed but rapidly rises toward the northwest to a height of more than 100 feet, when the dip changes, bringing the sandstone down again to the base of the hill half a mile to the northwest. The wagon road follows along the top of the saccharoidal sandstone as it passes over the axis of the anticline.

On Brown Branch, a tributary of Roasting-ear Creek from the southwest in section 8 (15 N., 12 W.), large quantities of the St. Clair marble outcrop on the hillsides for a mile and a half above its mouth. One of the finest exposures for quarrying is on the west side of the stream in section 18 (15 N., 12

W.), the northeast quarter, a little more than half a mile above Brewer's mill; at this place the marble is exposed on the point of the hill in fine ledges, where it has a total thickness of 45 feet, and a dip of 10° N. 25° W. It has a pinkish gray color, and near the middle of the bed there is a light red band from 2 to 3 feet thick which is slightly fossiliferous and of homogeneous texture.

On the hill north of Roasting-ear Creek and opposite the mouth of Brown Branch, the marble is 30 feet thick and lies near the top of the hill. It is underlain by 160 feet of Izard limestone, beneath which is an exposure of 15 feet of saccharoidal sandstone at the base of the hill.

In 15 N., 12 W., section 7, the marble outcrops on the point of the hill at Mr. Stevens' house. North of this exposure is an east-west fault with the downthrow on the north side; this fault cuts off the marble so that it does not outcrop north of the fault, nor does it appear in the ravine entering Roasting-ear Creek from the north. Marble is exposed along the south side of the creek in section 7 (15 N., 12 W.), and in sections 12 and 1 (15 N., 13 W.). On the south side of the creek in section 1, 100 yards west of Morgan Norman's house and about the same distance from the creek, is an exposure of 2 feet of St. Clair marble (the bottom concealed) of a red color and containing many well preserved fossils. This bed underlies 10 feet or more of the red St. Joe marble from which it is separated by a bed about two feet thick of greenish shaly, siliceous rock containing pebbles.

Along Bear Pen Hollow, the small tributary entering Roasting-ear Creek from the north in 15 N., 13 W., section 1, is a continuous exposure of St. Clair marble from near the mouth almost to its head. In some places it forms perpendicular bluffs, while in other places the successive outcropping of the different layers forms a terraced slope; gentle local folds cause the marble to outcrop in some places in the bottom of the valley, in others on the hillsides. It varies in thickness from 10 feet to more than 50 feet. On the points of the hills between the main hollow and some of the branch ravines the marble is

uncovered for a hundred yards or more back from the ravine. It lies in good position for quarrying, and is apparently of good quality.

No marble is exposed at the mouth of Bear Pen Hollow, where it is apparently below the water-level, although possibly only concealed by the chert debris, as it outcrops at the big spring on the north side of the creek a short distance west of the mouth of Bear Pen Hollow.

West of section 1 (15 N., 13 W.), no outcrop of marble was observed on the north side of Roasting-ear Creek; but on the branch entering it from the southwest in sections 2, 3, 10, and 11, it is exposed in large quantities, the most promising outcrop being in section 10 on the east side of the creek along Mr. Avery's fields, where it occurs in massive ledges.

North Sylamore Creek.—The strata along North Sylamore Creek are considerably folded, more noticeably so on the lower part of the creek than on the upper. A fault or displacement of the strata was observed in 15 N., 11 W., section 3, and local faults are liable to occur elsewhere in the basin.

The St. Clair marble outcrops near the top of the hill in sections 9 and 10 (15 N., 11 W.), on the south side of the creek, where it is overlain by a thin bed of Sylamore sandstone, which in some places is black. In sections 4 and 5 (15 N., 11 W.), on Mill Creek and the short ravine east of it, is an exposure of the marble, which has a bright red hematite color. The bright color and fine texture of the marble at this place, as far as can be judged from a surface examination, promise a marble of fine quality, and one which would find a ready demand in the market. The red marble is underlain by marble of the same pink color as that found elsewhere in the region. The exact thickness of the red part could not be ascertained, but in some places on the Mill Creek side of the hill, it is not less than twenty-five or thirty feet; the entire thickness of the bed, including the underlying pink, is about seventy-five feet. It outcrops in heavy layers, which probably are still heavier in the interior of the bed—that is, many of the stratification planes may be due to weathering influences, as they are elsewhere.

The heaviest layer exposed is more than five feet thick, the bottom being concealed, and it is so firm, solid, and even on the weathered surface that it is difficult to break off even a small piece with a hand hammer. It is fossiliferous throughout, the fossils consisting of crinoid stems, brachiopods, and bryozoans. The upper part of the bed on the Mill Creek side is intersected by numerous irregular veins and patches, which are more strongly impregnated with hematite than the body of the rock, thus giving it a variegated and somewhat fanciful appearance. The lines of beauty, however, are lines of weakness, and thin slabs from this layer could not be used safely unless backed up by other material. In the ravine east of Mill Creek, section 4, the southwest quarter, only the top of the bed is exposed in the bottom of the ravine, the underlying rocks being concealed by chert debris.

The red color in this marble is due to red hematite, as is shown by the following analysis:

Analysis of red St. Clair marble from North Sylamore Creek.

	Per cent.
Lime (CaO)	52.03
Magnesia (MgO)	.51
Ferric oxide (Fe_2O_3)	2.98
Alumina (Al_2O_3)	.62
Silica (SiO_2)	1.94
Phosphoric acid (PO_4)	.25
Potash (K_2O)	.30
Soda (Na_2O)	.29
Loss on ignition (carbon dioxide and volatile matter)	41.17
Total	100.09
Water at 110°-115° C	0.19
Calcium carbonate ($CaCO_3$)	92.48

At the base of the hill below the marble on Mill Creek, is a splendid water-power furnished by a large spring, the water from which has a heavy fall to North Sylamore Creek.

On the north side of North Sylamore Creek, just below the mouth of Mill Creek, an outcrop of red marble somewhat similar to that on Mill Creek is reported.

Small weathered exposures of the St. Clair marble occur on North Sylamore for some distance above Mill Creek, but none of any commercial importance was observed above township line 15 N. A red marble occurs about the head of the creek, but it is the St. Joe marble of Lower Carboniferous age. No St. Clair marble occurs north of the valley of North Sylamore Creek unless it be a mere trace.

Big Creek (*Range 14 W.*).—On Big Creek, Searcy county, the rocks have a marked dip to the south, so that the marble horizon which is 400 feet or more above the creek at the mouth is at the creek level in 15 N., 14 W., section 17. The rocks are gently folded and possibly faulted both above and below the confluence of Big and Long Creeks.

On the lower course of Big Creek no St. Clair marble of economic importance was observed. In some places it appears to be absent entirely, while in others it is represented by a few rounded boulders at the base of the chert.

On Spring Creek, north of Big Flat, the marble outcrops in several places. The details of the outcrop on Spring Creek were not worked out, and as the rocks are both folded and faulted, the outcrop as shown on the map is correct only in a general way. The marble is exposed high on the hills on each side of the creek near the mouth and on the north side of the creek on its upper course. A fault with the downthrow on the south side carries the marble horizon below the drainage level on the south side of the creek east of the Big Flat-Mountain Home road.

In Hickory Hollow, the tributary from the west which drains the southwest part of 16 N., 14 W., the St. Clair marble is exposed in sections 30, 31, and 32. Above the two fine springs in section 32, the southwest quarter, the marble outcrops along the base of the hill for a mile. It is but partly crystalline and has a loose crumbling texture at the surface.

On Cedar Creek, a tributary of Big Creek, in the north part of 15 N., 14 W., the marble is on the top of the hill near the mouth of the stream, but owing to local folds it occurs at various elevations farther up-stream. It extends almost to the

head of the creek in section 1, and is underlain by a heavy bed of blue Izard limestone.

On *Long Creek*, Searcy county, and on its two principal tributaries from the south—Turkey Creek and Seller's Creek—in 15 N., 14 W., the St. Clair marble outcrops in a bed of variable thickness; no measurements were made, but both the marble and the underlying blue limestone are thinner than in Stone county. The most eastern exposure observed on Long Creek is close to the Searcy-Stone county line near the fork of the Marshall and Clinton roads. Through sections 13 and 24 (15 N., 14 W.), the marble is mostly concealed, but through sections 14, 15, and 16 the exposure is continuous except in a few places where it is concealed by chert fragments.

On Big Creek, about half a mile above its confluence with Long Creek, at the big spring in section 17 (15 N., 14 W.), an acre or more of the marble is exposed, either totally bare or with a slight covering of soil; on the hill north of the creek below the spring it is exposed in a massive ledge from fifteen to twenty-five feet thick.

Up-stream from the spring the strata are folded somewhat, bringing the marble horizon below the drainage level in some places, and above it in others. The first exposure of the marble above the spring is on the axis of a low anticline in section 18 (15 N., 14 W.) and section 13 (15 N., 15 W.).* The last exposure of the marble found in ascending Big Creek is in sections 13 and 14 (15 N., 15 W.), on the Barren Hollow tributary.

(The Harrison map sheet.)

South side of Buffalo River, west of Big Creek (*Searcy county.*)—On the south side of Buffalo River at the Narrows (17 N., 15 W., section 13) the St. Clair marble is entirely wanting, and the thin bed of Sylamore sandstone rests directly upon the blue Izard limestone. Small weathered exposures of the marble occur on Spring Creek, Bald Knob Branch, Little Rock Creek, and Rock Creek, and larger outcrops occur on Brush Creek, on the lower part of Bear Creek, and along the south

*The upper cour of Big Creek is shown on the Harrison map sheet.

side of Buffalo River above Bear Creek as far as 16 N., 17 W., section 36, where it dips beneath the surface close to Grinder's ford on Buffalo River. Going up Buffalo Fork from Grinder's ford the marble does not appear again until section 9 of 15 N., 18 W., is reached, a mile above Richland Creek. At Cave Creek post-office on Cave Creek, at the old saltpeter cave, there is a ledge 12 feet thick with the bottom concealed.

No outcrop of the St. Clair marble was observed on the south side of Buffalo, west of Cave Creek, yet as it was found on the north side, it is probable that small local deposits may occur on the south side ; such beds, however, are not likely to be of much economic importance.

North side of Buffalo River.—On the north side of Buffalo River the St. Clair marble occurs only in isolated exposures, and not in a continuous bed, as does the St. Joe marble.

The most eastern exposure north of the river is on the south side of Rush Creek, opposite Rush post-office, on the north side of a small ravine which opens into Rush Creek hollow from the west. It occurs as a loose, shelly, fossiliferous deposit a few feet in thickness between the Izard limestone and a thin bed of Sylamore sandstone.

It occurs on Tomahawk Creek at Baker's gin in 16 N., 16 W., section 18, where it is of a light red color and highly crystalline. It is overlain by a bed of Sylamore sandstone about ten feet or more in thickness. The St. Clair marble outcrops on the lower part of Tomahawk Creek, the finest exposures being on the south side of the creek, much of that on the north side being concealed by the broken chert.

There is a small exposure of the St. Clair marble on the north side of Buffalo River, about a quarter of a mile below the mouth of Tomahawk Creek. It outcrops at the base of the hill on the south side of a fault in the strata. The St. Joe marble occurs on the hill on the north side of the fault more than 100 feet above the St. Clair. The cave at the base of the hill is in the St. Clair marble. (See chapter on Faults.)

The marble outcrops on Dry Creek, in 16 N., 16 W., section

30, where it has a light gray color, and is much disintegrated on the surface.

At St. Joe is the largest exposure of St. Clair marble of any observed on the north side of Buffalo River. One mile above St. Joe it occurs at the base of the hill on both sides of Mill Creek. It outcrops in ledges from 3 to 10 feet in thickness, the total thickness of the bed at this place being 20 feet, but it increases to 30 or 40 feet a half mile up the creek. The surface is but slightly disintegrated, but the loose fragments contain numerous irregular seams, which are apparently due to weathering influences. The Arkansas Marble Company did some work here, but it was all in the loose fragments, and no opening at the present is made in the rock in place. The samples taken for crushing tests and for analyses (see pp. 216–221.) were from these fragments. The marble outcrops on both sides of the creek through section 18 (16 N., 17 W.), but does not extend west of the range line.

The only outcrop observed north of St. Joe is in Rocky Hollow, a tributary of Pine Hollow, in 17 N., 18 W., section 12, where it is only two or three feet in thickness and entirely disintegrated on the surface, occurring as a crumbling mass of calcite crystals.

On Jimison's Creek, in 16 N., 18 W., sections 23, 24, 25, and 26, the bed is 30 feet thick and resembles that at St. Joe.

The St. Clair marble outcrops on the hills north of Mount Hersey, and on the north side of Little Buffalo River below Jasper, in 16 N., 21 W., section 26, the latter being the most western outcrop of this marble observed in the state. The thickness at the latter locality does not exceed 10 to 12 feet, and the areal exposure is small. It occurs on the axis of a small anticline where it dips beneath the water-level under a bed of yellow crumbling Eureka shale on the down-stream side, and is concealed by debris on the upper side.

CHAPTER XIX.

THE ST. JOE MARBLE.

The St. Joe marble is the name given by the State Geologist to the prominent bed of red limestone which occurs widely distributed over nearly all the counties of Arkansas north of the Boston Mountains. It is so named from the village of St. Joe, in Searcy county, Arkansas, where there is a typical exposure, and where it was first studied by the Survey.

Geologic position.—It is situated at the base of the Boone chert series, of which it forms a part; hence it is at or near the base of the Lower Carboniferous rocks in this state. It is underlain by the Eureka shale, where that formation occurs, otherwise by the Sylamore sandstone or by Lower Silurian rocks. In the eastern part of the marble area of the state it overlies the St. Clair marble, from which it is separated in most places by a thin bed of shale or sandstone; west and north of the borders of the St. Clair marble it overlies the saccharoidal sandstone, with which in some places, in the absence of the shale, it is in direct contact.

Where the Eureka shale and the Sylamore sandstone are absent, the St. Joe marble necessarily forms the base of the Lower Carboniferous rocks, and if the shale and sandstone are Devonian it forms the base of the Lower Carboniferous over the whole region. Dr. H. S. Williams, who has examined the fossils collected by the Survey in North Arkansas, says of the St. Joe marble: "The fossils obtained from this limestone belong to the fauna described from further north in Missouri and Iowa as Burlington, the earlier stages of the fauna of the Siliceous group of Tennessee—a later fauna than the Chouteau or Kinderhook faunas."* The same writer in another place, speaking of the entire chert series, of which the St. Joe marble

*Letter to the State Geologist, December 1, 1890.

forms the base, says that paleontologically it includes the Burlington limestone of Iowa and the lower Archimedes, or Keokuk of Hall.

Thickness.—The thickness of the St. Joe bed throughout the greater part of the area in which it occurs is from 25 to 40 feet. But as there is in many places no definite line of demarcation between the marble and the overlying chert, the upper limit of the marble is a somewhat arbitrary one. In some places in the eastern part of the area the chert occurs resting directly on the Silurian rocks, showing the entire absence of the St. Joe; while at other places, as at one place in the vicinity of Marble City, the chert is 100 feet and at another it is 250 feet above the bottom of the marble; in such cases, however, the upper part of the bed is of gray limestone similar to that interbedded with the chert elsewhere, but no sharp line can be drawn between the red marble at the base and the gray limestone overlying it, for the two gradually merge into each other.

Considering the St. Joe marble as that part of the bed of red colored limestone at the base of the Boone chert which is entirely free from chert, it occurs throughout the greater part of the central marble-producing part of the Paleozoic area of North Arkansas with an average thickness of from 25 to 40 feet and a maximum thickness in Newton county of about 100 feet.

Color.—The body of the rock varies from a light pink to a dark chocolate color, interspersed with spots of white, gray, or pea-green. In color it more nearly resembles the Tennessee marbles than any other and like them it embraces many varieties. A comparison of a collection of different varieties with a collection of the Tennessee marbles shows the latter to average a little darker in colors.

Varieties.—A description of all the varieties of the St. Joe marble would be a description of nearly every exposure, for there is a great variety in color, texture, structure, and general appearance of the marble from the different localities.

Only such as are considered typical or strongly marked varieties will be described in this place; other varieties will be

described under the head of distribution of the St. Joe marble in connection with the locality where it occurs. (1.) The *encrinital* (synonyms—encrinal, encrinitic, crinoidal) is one of the handsomest and fanciest marbles in the state. In nearly all places the St. Joe marble contains fragments of fossil crinoid stems, but in some places these fragments are so numerous as to form a considerable part of the rock; it is in such places that the marble is called encrinital. The fossils vary in size from those an inch in diameter to some so small as to be scarcely visible to the naked eye. The body of the rock is red and the fossils are white crystallized calcite. On the polished surface this contrast in color brings out the details of the structure of the fossils with remarkable clearness. In general the crinoid stems occur in all conceivable directions, but in some places they nearly all lie in one direction like a bundle of fibres; hence the cutting of the stone often has much to do with its appearance, as it is possible in some places to cut it in such a way that the fossils on the polished face may have either circular, elliptical, or rectangular outlines. When the stone is so cut as to show the fossils in circular outlines, a larger number is exposed over a given area; but when cut to show the fossils in rectangular outlines they form a larger proportional part of a given area. In the former case the stone is darker colored and in the latter case it is lighter; thus both the color and the general appearance of the finished stone depends upon the direction of the section across its bedding. In some places the fossils are more durable than the body of the rock and the weathered surface is thickly studded with pieces of crinoid stems.* The occasional presence of large brachiopods or bryozoans or of narrow veins of white or black calcite gives variety to the surface. The encrinital marble closely resembles the Dougherty or Hawkins county marble of Tennessee, but differs from it in having the white patches more clearly defined and more regular in outline. There is a typical exposure of it at St. Joe.

(2.) Another variety of the St. Joe marble may be called

*They are called "shirt buttons" by some of the people living in the region.

the *chocolate* marble on account of its color. It contains very few fossils, is homogeneous, fine-grained, highly crystalline and takes a fairly good, but in some localities not a brilliant polish. This lack of brilliancy is apparently due to amorphous particles composed largely of iron oxide, which result wholly from weathering influences and may not occur in the interior of the bed. The appearance of the stone on a ground, polished, or rock face is pleasing. While it lacks the style of the more mottled variety, it has a modest richness that would make it more desirable for large surfaces. It not unfrequently has a narrow yellow, white, or black vein running through it, and in places is found grading into the preceding variety.

(3.) A third variety of the St. Joe, closely allied to the preceding, is the flesh-colored marble, which is likewise homogeneous, finely but more completely crystalline, and slightly fossiliferous.

(4.) Of the *party-colored* marbles there are several varieties, one of the most common being of a reddish brown and light gray color, the brown forming the body of the rock and the gray occurring as bands or patches scattered irregularly through it. It is in some places without fossils, while in others it is filled with crinoid stems, the fossils being equally numerous in both colors. There is apparently no line of weakness between the colors, which in some places shade into each other, while in others they are separated by a sharply pronounced line. Another variety of party-colored marble has purplish brown and light green mottlings. It is very hard, compact, and finely crystalline, having the two colors often interwoven with such a charming irregularity that sometimes remarkably fantastic forms appear. No doubt some interesting and attractive figures would be found in working up a quantity of this marble. The two colors weather evenly and work equally well, and there is apparently no difference in the texture of the two. Another variety of the party-colored St. Joe marble is found in only one place—on the Marshall Prairie branch of Clear Creek, northeast of Western Grove. In color it closely resembles the last variety described, except that the mottling is of gray in-

stead of green, while the crystals are much larger and slightly rounded. In crystalline texture and tenacity it strongly resembles the St. Clair marble. The purplish tint so closely resembled the manganese color that it was examined chemically for that substance, but only the merest trace was found, while one specimen contained 0.44 and another 1.26 per cent. of iron oxide. Another rather handsome variety, having a chocolate colored body with patches of apple-green, occurs on Hog Creek south of Valley Springs. The surface rock contains too much amorphous matter to take a good polish, but this may be due to partial decay, and the rock may be more crystalline in the interior. A partial chemical analysis of the two colors separately showed in the red 2.12 per cent., and in the green 1.19 per cent. of ferric oxide. The iron was computed as ferric oxide but not proven to be such, and while the iron in the red colored is thought to be in the ferric state, that in the green is supposed to be a ferrous salt. A somewhat similar variety occurs at Marble City, but in the latter the chocolate colored body of the rock is more crystalline and the green is in nearly regular stripes perpendicular to the bedding planes, while in the Hog Creek variety the green is in irregular patches parallel to the bedding planes.

Gross structure of the formation.—In general the St. Joe marble does not occur in such massive layers as the St. Clair, in most places the surface marble being in layers from an inch to ten inches in thickness. How many of these dividing planes are due to atmospheric influences does not appear, but no doubt some, possibly many, of them disappear in the interior of the bed. In a number of places on the more abrupt slopes it occurs in solid layers from four to eight feet thick, which will without doubt prove to be the case in many other places beneath the partially decayed surface rock.

In many places throughout the central and western part of the marble area the St. Joe marble is distinguished topographically by outcropping in perpendicular, sometimes overhanging bluffs. These bluffs of "red limestone" are prominent features in the landscape in Marion and Carroll counties. The

accompanying figure (Plate XIV.) is a typical representation of one of these bluffs. Plate XVII. shows a weathered remnant of one of these bluffs and suggests their origin, that is, the top of the bed is much more durable than the bottom; the latter disintegrates and being washed away by the rains, leaves the top overhanging until it breaks down by its own accumulated weight.

Density.—The St. Joe marble is finer grained and harder than the St. Clair, yet differs from it but little in density. In the following table are given the specific gravities and weights per cubic foot of a number of specimens, determined by different methods.*

Specific gravities and weights of St. Joe marble.

Locality.	Specific gravity.	Weight per cubic foot.
	Common method	
St. Joe, Searcy county	2.7072	169.20
St. Joe, Searcy county	2.6972	168.58
St. Joe, Searcy county	2.7120	169.50
Marble City, Newton county	2.6905	168.26
Marble City, Newton county	2.6861	167.88
Rhodes' Mill, Boone county	2.7151	169.69
Rhodes' Mill, Boone county	2.7112	169.45
	Gillmore's method	
Rally Hill, Boone county	2.6753	167.21
Powell, Marion county	2.7160	169.75
Marble City, Newton county	2.6820	167.63
Boomer Hollow, Newton county	2.7179	169.86
Average	2.6985	168 66

The following figures show that the St. Joe marble has about the same density as the Tennessee, Vermont, and Italian marbles, all of which are lighter than the Tuckahoe marble of New York.

*By the common method, the specific gravity equals the weight of the specimen in the air divided by the difference between the weight in air and the weight in water. By Gillmore's method specific gravity equals weight of dry specimen in air divided by the difference between the weight of the stone saturated with water, in air, and the weight in water. App. II. of the Annual Report of the Chief of Engineers, U. S. A., for 1875. The weight of water in all cases is assumed to be 62.5 pounds per cubic foot.

The results obtained from the first seven are the averages of ten samples in each case; the last four were obtained from one sample each.

ST. JOE MARBLE, HARDING SPRING, EUREKA SPRINGS.

Specific gravities and weights of other marbles.

Locality.	Specific gravity.	Weight per cubic foot.
Concord quarry, Tennessee	2.710	169.4
Hercules quarry, Tennessee	2.696	168.5
Crescent quarry, Tennessee	2.691	168.2
Common Italian*	2.690	168.2
Dorset, Vermont*	2.635	164.7
Dorset, Vermont*	2.683	167.8
Tuckahoe, New York*	2.800	175.0
Tuckahoe, New York*	2.875	179.7
Georgia marbles†	2.724	170.0

Composition.—The chemical analyses given in the accompanying table show the St. Joe marble to be a comparatively pure carbonate of lime.

Analyses of St. Joe marble.‡

Constituents.	Marble City. Per cent.	Rhodes' Mill. Per cent.	Tomahawk Creek.‖ Per cent.	St. Joe§ crinoidal. Per cent.
Residue insoluble in hydrochloric acid	0.800	0.835	3.03	1.16
Titanic oxide (TiO_2)	trace	trace	....	
Phosphoric acid (P_2O_5)	0.02¶	0.009	....	
Alumina (Al_2O_3)	0.009	0.024	0.18	
Ferric oxide (Fe_2O_3)	0.051	0.058	0.70	
Manganese oxide (MnO_2)¶	0.015	0.071	....	
Zinc oxide (ZnO) present, but not determined	......	....	....	
Potash and soda	0.054	0.005	0.32	
Magnesia (MgO)	0.190	0.160	0.46	
Lime (CaO)	55.390	55.340	53.46	
Loss on ignition (CO_2)	43.740	43.630	42.30	
Total	100.272	100.177	100.38	
Carbonate of lime	98.91	98.82	95.46	98.73

*From Appendix II. of the An. Rep. of the Chief of Engineers, U. S. A. for 1875, p. 35.

†From the Blue Ridge Marble Company's circular, 1890, p. 101.

‡The first two analyses were made for the Survey by W. A. Noyes, Rose Polytechnic Institute, Terre Haute, Indiana; the last two by R. N. Brackett, Chemist of the Survey.

‖Chocolate colored; specific gravity 2.6744; weight per cubic foot 167.05 pounds.

§Partial analysis only.

¶Manganese was calculated as manganese dioxide but not proven to be such.

The Marble City specimen was obtained from the ledge from which the sample was taken for the Washington Monument; the Rhodes' Mill specimen was from the ledge from which samples were sent to the New Orleans Exposition. Both are of the mottled chocolate and gray colored variety.

A partial analysis of a light gray sample from a tributary of Flat Rock Creek, Newton county, showed it to contain 56.48 per cent. of lime and only 0.20 per cent. of matter insoluble in dilute hydrochloric acid.

The analyses show that the percentage of possibly injurious substances in the marble is very small. The alumina, which is most to be avoided in a building stone, exceeds one tenth of one per cent. in only one specimen, while in another it falls below one-thousandth of one per cent. The iron if present as ferric oxide may serve as a bond of strength rather than weakness; and even if present as ferrous carbonate or pyrite the quantity is too small to seriously injure the stone. Some of the iron is undoubtedly ferric, as shown by the reddish brown color.

Strength.—Tests made on the St. Joe marble show that its resistance to crushing is beyond the average for marbles. Twenty-seven tests were made on seven samples, three of which were duplicates. The first two samples are the encrinital marble from St. Joe; the next the chocolate colored marble from St. Joe, both from the surface and not perfectly sound; the fourth and fifth variegated crinoidal marble from Marble City, from the ledge from which the sample was taken for the Washington Monument; the sixth and seventh are from Rhodes' Mill in Boone county, and similar to the samples sent to the New Orleans Exposition. All the samples are of surface marble and were broken from the ledges by a heavy hammer which necessarily shattered the rock to some extent; especially is this true of the last of the St. Joe and the first of the Marble City samples, in which the cracks were visible to the eye. Under these conditions there can be little doubt that the figures show results much below what would be obtained from sound samples sawed from the interior of the bed.

Crushing strength of St. Joe marble.

Test.	Locality.	Height of test cube, in.	Area, square inches.	Total stress, pounds.	Stress sq. inch, pounds.	Average stress per sq. inch, pounds.
1.	St. Joe, encrinital	1.440	2.196	24,200	11,020	11,265
2.		1.433	2.242	24,370	10,870	
3.		1.435	2.206	29,000	13,150	
4.			2.246	22,500	10,020	
5.	St. Joe, encrinital	1.530	2.283	24,500	10,730	10,448
6.		1.529	2.287	23,800	10,410	
7.		1.515	2.291	25,800	11,270	
8.		1.116	2.282	21,400	9,380	
9.	St. Joe, chocolate	1.525	2.263	41,000	18,100	17,835
10.		1.530	2.391	42,000	17,570	
11.	Marble City, crinoidal	1.584	2.398	16,000	6,670	8,983
12.		1.590	2.336	20,600	8,820	
13.		1.600	2.320	29,500	12,720	
14.		1.586	2.384	26,500	11,120	
15.		1.753	2.307	14,500	6 290	
16.		1.528	2.304	18,500	8,030	
17.		1.540	2.269	20,500	9,040	
18.		1.532	2.292	21,000	9,170	
19.	Marble City, crinoidal	1.508	2.475	22,000	8,888	10,380
20.		1.520	2.498	27,700	11,090	
21.		1.480	2.459	25,000	10,170	
22.		1.520	2.589	29,000	11,200	
23.		1.517	2.579	27,200	10,550	
24.	Rhodes' mill, encrinital	1.520	2.552	46,000	18,030	15,780
25.		1.520	2.329	31,500	13,530	
26.	Rhodes' mill, encrinital	1.520	2.579	33,500	13,000	14,400
27.		1.520	2.533	40,000	15,800	

Crushing strength of other marbles.

	Strength per square inch.
Italian*	11,250
Italian*	13,062
Dorset, Vermont*	7,612
Dorset, Vermont*	8,670
Georgia; average of six tests†	10,200
Georgia; highest of six tests†	12,210
Geogia; lowest of six tests†	8,330
Cherokee, Georgia‡	10,976
Creole, Georgia‡	12,078
Etowah, Georgia‡	10,642

*By Q. A. Gillmore, App. II. An. Rep. Chief of Engineers, U. S. A., 1875.

†By Prof. J. B. Johnson, laboratory of Washington University, from circular of the Blue Ridge Marble Company, p. 100.

‡Ordnance Department, U. S. A. Watertown Arsenal, Mass.; from the circular of the Blue Ridge Marble Company, p. 99.

It will be seen from the foregoing figures that the St. Joe marble ranks in crushing strength above the Italian, Vermont, and Georgia marbles, which are the leading ones in the American market. The difference is even greater than that shown by the figures above, as the tests on the St. Joe marble were upon sledge-hammer samples of surface rock, while the others were upon selected samples of sawed rock.

Absorption.—The value of a stone for standing exposure depends in a large measure upon the amount of moisture which it will absorb. A number of specimens were tested for the ratio of absorption, as follows:

Seven different samples of the stone were collected from four different localities, and from each specimen were taken three pieces of different weights and shapes, from a cube to a thin strip a quarter of an inch thick. These were first weighed and then dried for an hour at a temperature of 225° F., and then reweighed. They were then immersed in water, from which they were taken and dried in coarse muslin and reweighed at the end of three hours, one day, three days, and sixty days, at the end of which time they were taken out, dried, and weighed again. Of the average of the three pieces from each sample at the end of sixty days it will be seen that the ratio and percentage of absorption are almost nothing.

Ratio and per cent. of absorption of the St. Joe marble after immersion for sixty days.

No.	Locality.	Ratio.	Per cent.
1	St. Joe encrinital	1 to 400	0.25
2	St. Joe encrinital	1 to 303	0.33
3	St. Joe chocolate	1 to 296	0.34
4	Marble City	1 to 175	0.57
5	Marble City	1 to 204	0.49
6	Rhodes' Mill	1 to 666	0.15
7	Rhodes' Mill	1 to 345	0.29
	Average	1 to 341	0.34

The column headed ratio shows the proportion by weight of water absorbed by the stone; for example, 400 pounds of the stone, absorbed one pound of water. The next column is

obtained from the first, and shows the per cent. by weight of water absorbed.

The ratio varies from 1 in 175 to 1 in 666, or from fifteen one-hundredths to fifty-seven one-hundredths of one per cent., with an average of 1 to 341, or thirty-four one-hundredths of one per cent.

*Ratio and per cent. of absorption of marbles from different localities**.

Locality.	Ratio.	Per cent.
Tuckahoe, N. Y.	1 to 298	0.34
Ashley Falls, N. Y.	1 to 280	0.36
East Tennessee	1 to 320	0.31
Isle La Motte, Vt	1 to 320	0.31
Rutland, Vt.	1 to 342	0.29

It will be seen on comparison of the foregoing lists that the St. Joe marble ranks fully up to the average in its low ratio of absorption, and if we except the weathered and shattered sample from Marble City (Nos. 4 and 5), it ranks ahead of marbles from other places in this respect.

Frost test by freezing.—The samples were weighed, placed in water for six hours, and then exposed alternately to freezing and thawing under the water for six times, or a total exposure to freezing of ten hours, at an average temperature of about 20° F., and a total exposure in water of one hundred hours, or about four days, at an average temperature of about 40° F. The freezing in each instance took place soon after exposure and before much of the surface water had evaporated. Ice crystals were found attached to the specimen in each instance. At the end of the experiment the pieces were dried and weighed, but no loss of weight due to action of the frost could be detected. Lack of time prevented a continuation of the experiment.

Brard's test.—Three small pieces of each of seven different samples were placed in a saturated solution of sulphate of soda (Glauber's salt) and boiled for one hour. They were then placed in a coarse sieve and exposed to the air at a tempera-

*From report by Dr. Hiram Cutting, State Geologist of Vermont.

ture of 70° F. for seventy-two hours (three days), then placed in clear, boiling water and boiled for one hour and finally dried at 225° F. and reweighed. The efflorescing of the salt with which the stones were saturated represents in a measure the action of frost.

Brard's frost test of St. Joe marble.

No.	Locality.	Weight* before boiling.	Weight after boiling.	Loss.	Loss per cent.	Average loss per cent.
1.	St. Joe, encrinital	109.436	109.300	.136	0.13	0.37
2.		44.170	44.083	.087	0.19	
3.		12.211	12.115	.096	0.78	
4.	St. Joe, encrinital	92.633	92.415	.218	.23	0.24
5.		49.314	49.232	.082	.16	
6.		22.375	22.302	.073	.33	
7.	St. Joe, chocolate	38.956	38.922	.034	.08	0.10
8.		40.487	40.427	.059	.15	
9.		65.481	65.434	.047	.07	
10.	Marble City	32.128	31.980	.148	.46	0.31
11.		74.433	74.158	.275	.37	
12.		97.903	97.795	.108	.11	
13.	Marble City	28.469	28.365	.104	.37	0.39
14.		58.844	58.481	.363	.62	
15.		108.464	108.276	.188	.17	
16.	Rhodes' mill	34.562	34.526	.036	.10	0.09
17.		46.645	46.590	.055	.12	
18.		100.257	100.221	.036	.04	
19.	Rhodes' mill	29.962	29.920	.042	.14	0.11
20.		46.552	46.502	.050	.11	
21.		61.904	61.854	.050	.08	

Owing to the little use of this method, no satisfactory results can be given for comparison. Partial results of some experiments conducted by Mr. Page with this process are given by Prof. Merrill,† but the loss is given in grains per cubic inch and with such small results that unless the weight of each cube were given the reduction would be uncertain. With the results as given, however, the close-grained and blue marble of Maryland and the blue limestone of Pennsylvania show a smaller loss than the St. Joe, while the "alum stone" marble of Maryland and the dolomitic marble of New York show about the same. As stated elsewhere in this volume, results by this process are somewhat uncertain, owing to the liability of chemical action.

*Weight in grammes.

†Stones for Building and Decoration, by G. P. Merrill, N. Y., 1891, p. 388.

Fire test of the St. Joe marble.—Samples of the stone were heated in a bath of molten lead to a uniform temperature of about 600° F. (twenty minutes taken for a piece of stone weighing 100 grms.), and then suddenly cooled by plunging into cold water. All of the specimens cracked badly and crumbled easily in the fingers at the edges where the stone was thinnest, the effect in each case varying as the crushing strength of the stone. No weights were taken to determine the loss by this method, as the stone showed such unmistakable signs of injury.

Dr. Cutting's experiments on marble and other building stones from different localities, show that the marble first showed signs of injury at a temperature from 900° to 1000° F. The wide difference in the results between Dr. Cutting's experiments and those made on the St. Joe marble may be due in large measure to the different methods of conducting the experiments. This marble is sought by the citizens to line the fireplaces of their chimneys because of its fire-proof properties, as they claim it will stand the fire much better than any other rock. It is also used to line fireplaces under steam boilers. Examination of the stone in fireplaces where it had been for many years subject at times to as great heat as it was possible to obtain from the use of oak and pitch-pine wood in an ordinary chimney, showed it to be uninjured. In several chimneys the large arch rock over the fireplace was cracked, but it is thought to be due rather to lack of skill in building the chimney, possibly in some instances due in part to lack of sufficient transverse strength in the stone.

Durability.—The tests for density, strength, composition, absorption, and by frost and fire throw considerable light on the durability of the St. Joe marble. To recapitulate briefly: in density it is equal to average marbles now on the market; in composition it is a comparatively pure carbonate of lime with a small percentage of impurities, and a very small quantity of any possible injurious substances; in strength it ranks above the average; in absorption it is an average; the frost tests were too unsatisfactory to make any comparison; the fire tests

in the laboratory show it to be below the average marble in resisting fire, yet local experience shows it to be a valuable rock in this respect.

As samples of the St. Joe marble were quarried as long ago as 1836, some idea may be gained regarding the effect of the weather on its surfaces. In the spring of 1890 the quarry from which the block was sent to the Washington Monument was visited; the only effect of the fifty-four years of exposure upon the surface left exposed at that time was a slight discoloration, the color being darker and not so bright. No signs of decay or weakness could be discerned, the marks of the drill being as plain and clear-cut as ever, and the thin knife edge of the marble, where it had split from the drill hole, was firm and solid.

In Elmwood Cemetery, between Marble City and Harrison, there is a marble slab put down by Eli Beller in 1849; the slab lies flat, is 3 feet long, 2 feet wide, and 2 inches thick. The upper surface of the stone is somewhat discolored, having turned darker, while on its edge there is but slight change of color; and the letters and figures are as sharp and clearly defined as when first made. There is no polish on it, but it is doubtful if it ever was polished. The dark color is thought to be due in great measure to a microscopic vegetable growth.

At Yardell is a large slab of marble that was formerly used for a currier's table; when it was quarried and how long it has been exposed to the weather could not be ascertained, but it certainly was in existence prior to 1857, for Dr. Owen speaks of seeing it at that time. He says*: "At a tan-yard on Davis' Creek, I saw a slab of this rock (marble) eight feet by two and a half, which had been got out for a currier's table. The predominating color of this rock is gray, mottled and clouded, with liver-colored spots and stains. This slab was dressed smooth, but not polished; when wet it exhibited, however, the hues and appearance which it would possess, if polished, and gave one a better idea of its tints and the variegated

*First Report of a Geological Reconnoissa ce of the Northern Counties of Arkansas, by D. D. Owen, 1858, p. 87.

aspect of its surface, than could be obtained from an inspection of the rock in its native bed." The weather seems to have had no effect on this stone, and it appears to-day much as it did in 1857.

On the old Vance place near Rally Hill is a chimney built of the St. Joe marble. It could not be ascertained more exactly when it was put up than that it was more than forty years ago. Except for the scratches from knives and boot heels, the polished arch rock and jambs are as bright and fresh as though recently polished. The part of the chimney exposed above the roof is made of slabs of the marble stood on edge, which are apparently as firm as when first erected.

In later years many headstones made of St. Joe marble have been placed in the cemeteries through Marion, Boone, Newton, and Carroll counties, but few of them are old enough yet to throw much light on the durability of the stone. It seems to be less liable to discoloration than the white and clouded Vermont and Italian marbles.

The evidence gathered from the surface exposures of this marble shows that it varies widely in its resistance to the atmosphere in different localities, and that the different varieties are affected in different ways. In some places it is exposed in solid massive ledges with comparatively smooth surfaces; in others it has a continuous unbroken face; in still others the outcrop is strewn with large boulders which have broken from the parent ledge. In many localities it occurs as thin slabs which increase in thickness in penetrating the bed. In their natural exposures the fine-grained, non-fossiliferous varieties have a smooth even surface. The fossiliferous varieties in general have a rough uneven face, caused by the fossils projecting from the surface; in some places, however, where it is very fossiliferous the surface is comparatively smooth, as the fossils weather evenly with the body of the rock. As a rule the lighter colored, finer grained, less fossiliferous varieties stand exposure best.

Adaptability of the St. Joe marble.—The brighter colored varieties of the St. Joe marble are pre-eminently suited for cab-

inet work, mantels, and interior ornamentation of different kinds. The less bright colored but variegated varieties would make desirable tiling, staircases, and wainscoting. The chocolate and flesh-colored varieties would make beautiful and valuable building stones, as well as trimmings for brick and stone buildings. The light-colored varieties are preferable for monuments and out door work as the deeper colored varieties change on exposure. There are so many varieties in shade of color, configuration, and texture that they will be found adapted to many different uses. As some of the varieties are unique in their appearance they will be sought for use in large buildings where a great variety of marble is desired in ornamentation.

CHAPTER XX.

The Distribution of the St. Joe Marble.

WHITE RIVER VALLEY BELOW AND INCLUDING PART OF BUFFALO RIVER VALLEY.

The St. Joe marble is distributed over a greater area than the St. Clair; in fact, in one form or another, the limestone at the base of the Boone chert formation extends over all the northern part of the state, although strictly speaking a considerable part of the area contains no marble.* It extends from near the Paleozoic border in Independence county, west across the northern part of the state into Indian Territory and into the southwestern part of Missouri. The marble throughout this region, however, is not equally good; indeed, it is more often worthless than valuable. It is in the central part of the marble area, in the Buffalo River and Crooked Creek basins, in Newton, Boone, Marion, and Searcy counties, that the finest and most valuable of the St. Joe marble occurs. As with the St. Clair, the St. Joe marble outcrops along the watercourses, and hence a detailed description of its occurrence can be most conveniently based on the drainage system of the country.

In Independence county the St. Joe marble has no economic value. It occurs in many places at the base of the chert, in some places from ten to fifteen feet thick, but it is always crumbling, full of seams, and of a dull gray color.

(The Mountain View map sheet.)

On the south side of White River, on Dry and Cagen Creeks, in 14 and 15 N., 9 W., are several small exposures where the

*In order to avoid the repetition of terms the word marble will be used as applying to the bed of limestone at the base of the Boone chert. (See p. 212.) As a matter of fact the outcrops of this limestone in many places are wholly or partly marble, while in other places they contain no marble, properly speaking.

marble has a fairly bright color, but its loose, shelly texture renders it of little or no value.

Sylamore Creek.—On South Sylamore Creek the St. Joe marble outcrops in three places. In 15 N., 11 W., section 28, on the south side of the creek near the church, and underlain by a bed of conglomerate, is an exposure of from fifteen to twenty feet of the St. Joe marble, the upper part of which is crumbling and full of seams; the bottom layers, from four to ten feet thick, are firm, solid, bright colored marble. In 15 N., 12 W., section 25, on the north side of Roasting-ear Creek, just above the confluence with South Sylamore, is an outcrop of the St. Joe marble five feet thick, with the upper part of the bed concealed by chert debris. It is shelly, has a dull gray color, and is of no value. In 15 N., 13 W., section 1, on the south side of Roasting-ear Creek, is an exposure of ten feet of red fossiliferous St. Joe marble, of a loose shelly texture on the surface, but promising firmer rock underneath.

A more detailed examination would doubtless show other and possibly better exposures of the St. Joe marble on South Sylamore and Roasting-ear Creeks than the ones mentioned, as the marble in some form extends over the entire area.

On North Sylamore Creek the St. Joe marble outcrops in considerable quantities about the head of the creek, but forms an inconspicuous and unimportant bed on the lower course of the creek. It occurs on the head ravines of Capps', Cole's, and Stewart's Forks of North Sylamore Creek, as a bed of red limestone 10 to 15 feet in thickness. The surface rock on all the outcrops examined has a loose, shelly, crumbling texture and is full of seams.

Leatherwood Mountain.—The St. Joe marble forms an almost continuous ledge around and near the top of Leatherwood Mountain. On the eastern part of the mountain it varies in color from pink to reddish-brown, is very crinoidal in places, full of seams and weathers into small rectangular blocks from two to four pounds in weight. It overlies a heavy bed of saccharoidal sandstone. The west end of the mountain has not been examined in detail. East of the mountains on the

high ridge extending through 17 N., 12 W., in the direction of Sugar Loaf Mountain, the marble outcrops in places, but it is generally of inferior quality.

White River, Baxter county.—North of Leatherwood Mountain there is an irregular, slightly rolling strip of country known as the Flat Woods, varying in width from two to four miles. The rocks exposed across this area are all of Silurian age, but a flexure in the rocks north and northwest of Lone Rock causes the Lower Carboniferous rocks—the marble, and chert that cap Leatherwood Mountain—to outcrop along the river at a lower level than the intervening Silurian flat. This depression in the strata is a local one; on the north side of White River the Silurian rocks are at a higher level, while on Stair Gap Bluff to the west and Matney's Knob to the east, the Silurian rocks are several hundred feet higher than they are midway between. Near the mouth of Mill Creek in 18 N., 13 W., section 20, the marble is 250 feet above the river; on Stair Gap Bluff, which is 600 feet high, the marble does not occur at all, while on Matney's Knob it is 1020 feet above the river, thus showing a depression on one side of nearly 800 feet and on the other of more than 350 feet. The marble is exposed on each side of Mill Creek in section 20 (18 N., 13 W.), in a bed from 30 to 35 feet thick. It is fossiliferous, of a reddish chocolate color, disintegrated on the surface but firm and solid a few inches below the surface. It extends west from Mill Creek nearly to the mouth of Buffalo River. East of Mill Creek and between the creek and Shipp's Ferry, there are two outcrops along the south side of the river, one on each side of the ravine known as Steep Gut.

Since the work of the Survey was finished in this region, quarries have been opened on these outcrops in 18 N., 13 W., sections 20 and 21, from which samples have been shipped to Chicago and elsewhere. Some of the parties opening the quarries report that the marble occurs in layers four to six feet thick, a short distance below the surface.

On Matney's Knob the marble outcrops seventy-five feet be-

low the top of the mountain, but it is much decayed and in places covered with broken chert.

There is a small outcrop of the marble on the north side of the river above Shipp's Ferry.

The localities described above in 18 N., 13 W., are the only points on the navigable parts of White River where the St. Joe marble has any economic value.

Big Creek, Searcy county.—On the lower course of Big Creek in 16 and 17 N., 14 W., the marble outcrops near the tops of the hills, but it is of poor quality and of dull color. Besides the fault on Spring Creek north of Big Flat, which is described in the chapter on faults, the strata are folded so that the marble horizon of that region, as shown on the map, is subject to modifications in some of its details.

(Harrison map sheet.)

South side of Buffalo River below Cave Creek, Newton county.—At the Narrows in 17 N., 15 W., sections 13, 14, and 34, the St. Joe marble is exposed in a bed 15 to 20 feet thick. It has a light red color but at the surface it is loose, shelly, and full of seams. In the high bluff north of the low gap, the Sylamore sandstone immediately underlying the St. Joe marble is but two or three inches thick and contains dark-colored pebbles. On the south side of the low gap the sandstone is calcareous and three to five feet thick. In both places it is underlain by a heavy bed of Silurian blue limestone.

There is a conspicuous outcrop of the red St. Joe marble in the bluff on Buffalo River, immediately below the mouth of Spring Creek, where it is underlain by a heavy bed of saccharoidal sandstone. It outcrops for a distance of half a mile or more in the bluff on the south side of the river above the mouth of Tomahawk Creek.

The St. Joe marble occurs on Hickory, Spring, Rock, Little Rock, Brush, and Bear Creeks, besides the numerous smaller tributaries; but no outcrops of special economic value were observed by the Survey, hence no detailed examination was made of this area.

A few miles above the mouth of Bear Creek in 16 N., 17 W., section 36, the marble horizon dips beneath the drainage level and reappears as a surface rock a mile above Richland Creek in 15 N., 18 W., section 9, from which point the outcrop is continuous as far as Jasper, except where concealed by chert fragments.

Cave Creek, Newton county.—But little marble is exposed at the mouth of Cave Creek, where the Silurian rocks extend to the tops of the hills, but in ascending the creek the marble occurs at a constantly lower level, until at Cave Creek post-office it outcrops near the base of the hill in a bed fifteen feet thick. It is overlain by black chert and underlain by the Eureka shale, which here contains black pebbles, some of which occur in the bottom layers of the St. Joe marble. The marble at this exposure occurs in thin, irregularly bedded slabs with a crumbling texture. It outcrops at intervals for nearly a mile up-stream (south) from the post-office, where it disappears beneath the overlying rocks.

The Silurian rocks on Cave Creek are highly siliceous, and form bold rugged bluffs on the lower course of the creek. In the base of the lone hill at the mouth of the creek is a bed of snow-white quartzite ten feet thick.

Between Cave Creek and Big Creek, the next considerable affluent of Buffalo west of Cave Creek, the marble outcrops at irregular intervals, noticeably in 15 N., 19 W., sections 3 and 4, on Lick Creek, and the two small tributaries of Buffalo River east of it.

Big Creek, Newton county.—The marble outcrops along Big Creek from its mouth to a short distance above the forks of the creek, a distance of more than three miles. At the mouth of Big Creek the marble is from forty to sixty feet above the creek, and is underlain by the saccharoidal sandstone. In 15 N., 20 W., section 12, near the center of the section, the Silurian rocks dip beneath the surface, and the marble appears along the base of the hills from this place to the forks of the creek in section 14 (15 N., 20 W.), where the sandstone rises to the surface again and outcrops for 300 yards along each branch.

On the branch flowing from the south, known as the left-hand prong of Big Creek, is the finest outcrop of St. Joe marble seen in this region. It forms a stratum twenty-five feet thick along the west bank of the creek; in some places it is perfectly solid, in others it is in slabs from two to four inches thick, with even bedding planes.

(Carrollton map sheet.)

Up Buffalo from the mouth of Big Creek the marble horizon is in many places concealed by the chert debris, but local exposures occur along the river and in the small tributaries. On the small creek from the south, in 16 N., 21 W., sections 25 and 36, an anticline causes the marble to outcrop near the water-level at the mouth of the creek, above which it rises to a height of nearly a hundred feet on the slopes, and again descends and dips beneath the surface below the steam sawmill, in the southern part of section 36. In the ravine south of Jasper, the red St. Joe marble is exposed along the watercourse for more than half a mile; at the mouth of the ravine, however, it is concealed by talus. The marble horizon extends a mile or more above Jasper, though but little of it is exposed on the south side of the river.

Between Big and Little Buffalo Rivers.—Small folds and faults occur along Henson Creek in 14 N., 21 and 22 W., where the marble outcrops the greater part of the way from the mouth of the creek to the northwest quarter of section 1 (14 N., 22 W). The Silurian saccharoidal sandstone is exposed underneath it on the lower part of the creek. In the northwest quarter of section 1 (14 N., 22 W.), near the upper limit of the marble on the creek is a small fault showing plainly in the marble exposure at Blue Bluff on the south side of the creek. The downthrow of about fifteen feet is on the southeast side, the red marble just appearing above the surface on that side, while on the north side of the break it is exposed over fifteen feet. The dip on the north side is 6° S. 30° E., and on the south side it is 18° S. 30° E.

The marble does not occur on Little Buffalo River south of

Henson Creek. Northeast of Henson Creek it outcrops at intervals all the way to the confluence with Big Buffalo. The rocks are folded in some places, in others they are faulted, all the details of which cannot be shown on the map.

On the south side of Big Buffalo River the marble horizon is close to the river nearly all the way from Boxley to the confluence of the Little Buffalo River, concealed in many places by the debris from the steep slopes, and in 16 N., 22 W., section 10, and the east part of section 9, concealed by a displacement of the strata. It outcrops on Steele Creek a mile from the river; on Indian Creek the southern limits have not been traced.

North of Big Buffalo River, from Boxley to Mill Creek.—The marble outcrops on the west side of the wagon road a quarter of a mile below Boxley and thence, close to the river nearly all the way to Mill Creek, except over a small area near the mouth of Sneed's Creek, where faults, or displacements in the strata, have carried the marble horizon below the river level. In some places the marble is but a few feet above the river; in others it is 300 to 400 feet above, yet the valley is so narrow that in no place is the marble outcrop far removed from the river. Thus in 16 N., 22 W., section 9, the marble on the south side of the east-west fault is 370 feet above the river, while on the north or downthrow side of the fault it is only from two to ten feet, yet on a horizontal projection the distance from the river is nearly the same in one case as in the other. As the fault lines were not traced out along Sneed's Creek, the details of the marble outcrop are not shown, nor could they be clearly shown on so small a scale. The marble is exposed on Clark, Villiens, and Clifty Creeks, in Cecil and Gaither Coves, as well as in the smaller ravines, but so far as observed it is full of seams containing earthy material at all these places.

(The Harrison map sheet.)

General features of the marble area north of Buffalo River.—There are large and extensive outcrops of fine marble on the north side of Buffalo River, from Jasper to near the mouth of

the stream. Both in the quantity and quality of the marble exposed it is probably unsurpassed by any equal area in the state. Although the tributaries are shorter and the area drained is smaller than that on the south side of the river, the marble outcrop is larger. The reasons for this are: (1) the general south dip of the rocks causes larger exposures along streams flowing south than along those flowing north; (2) nearly all the faults in the region have the downthrow on the south side; (3) the general level of the country being lower on the north side, the lateral and terminal ravines are more numerous and erosion has uncovered more marble. The chief tributaries are Mill (Newton county), Wells, Davis, Mill (Searcy county), Tomahawk, Water, Panther, Rush, and Clabber Creeks, on all of which the marble outcrops.

Mill Creek, Newton county (*Marble City region*).—Mill Creek drains the southern and southwestern part of 17 N., 20 W., and the northwest part of 16 N., 20 W., a region abounding in marble and limestone. The tributary on the east side near the mouth, called Flat Rock from the broad sheets of Silurian sandstone in the creek bed, flows between hills containing heavy beds of marble. In section 32 (17 N., 20 W.), the northeast quarter, the marble is 75 feet thick, the lower part consisting of thin much-weathered slabs of the red marble, the upper part of a gray colored marble in heavier layers. In section 33, the southwest quarter, a section on the hill on the north side of the creek shows heavy beds of marble and limestone.

Section on Flat Rock Creek.

	Feet.
Gray limestone of the Boone chert formation	110
St. Joe marble	70
Siliceous limestone	10
Saccharoidal sandstone	80

Some layers of the gray limestone consist of a white amorphous body, with crystalline and oölitic particles interspersed through it. A few of the upper layers of the red St. Joe marble are each two or three feet in thickness, but most of the bed on the surface is in layers from two to four inches thick.

In section 27 (17 N., 20 W.), the southwest quarter, on a tributary of Flat Rock, which heads in the Fodder Stack Mountain, is a valuable variety of the St. Joe marble, which is light gray in color, highly crystalline, very firm and compact, and almost pure calcium carbonate. A partial analysis of a sample showed it to contain only 0.20 per cent. of residue insoluble in hydrochloric acid, the remainder being pure lime carbonate. It is fossiliferous, numerous crinoids and brachiopods showing on the surface; in large pieces it breaks with difficulty, but chips easily and takes a beautiful polish. Some pieces have been quarried, but by whom and for what purpose is not known to the Survey. In the bottom of the ravine, 250 yards further to the northeast, in the same section, is some of the brightest colored marble observed anywhere in the state, but as it occurs in thin strata, irregularly bedded, and contains earthy seams and intercalary chert, it is of doubtful commercial importance. Weathered exposures of the red marble occur in section 28 (17 N., 20 W.), in another ravine of this tributary, along the road from Marble City to Well's Creek, and in section 34 on the southern or main branch of Flat Rock Creek. On the hill south of Flat Rock Creek the Boone chert is almost entirely replaced by the gray limestone, which is here more than 200 feet thick; no chert except surface fragments occurs, yet on the south side of the same hill, on the head of Wells' Creek, the hillside is covered with chert fragments and but very little limestone is exposed.

On the west side of Mill Creek, in 16 N., 20 W., section 6, a section on the south side of the hill, next to Buffalo, shows 150 feet of Calciferous sandstone at the base, 70 feet of red marble in strata from two to twelve inches thick, and 230 feet of chert and gray limestone at the top, while on the Mill Creek side of the hill there is but a slight exposure of the marble, most of it being covered by chert debris.

Harp Creek is a tributary of Mill Creek from the west, in 17 N., 20 W., sections 31, 29, and 30, and 17 N., 21 W., sections 24 and 25. The south end of the hill between Harp Creek and Mill Creek consists of a saccharoidal sandstone

base overlain by marble, and capped with chert, the exposure on the Harp Creek side being much more prominent than on the Mill Creek side, where it is partly covered with chert. In the middle of the west part of section 29, on the Harp Creek side of the hill, the St. Joe marble varies in color and texture; the bed is nearly 100 feet thick, the bottom layers, ten to fifteen feet, being shaly, yellow, soft, and crumbling; the next eight or ten feet of a purplish red color, in thin solid slabs from one to three inches thick, overlying which is the main body, 70 to 80 feet in strata from two to five feet thick, varying in color from dark reddish brown to light rose colored, with some bands of gray. It is nearly all fossiliferous, crinoid stems being the most abundant.

The outcrop along this hillside through the east part of section 30 and west part of section 29 is from 100 to 300 yards wide and in good position for quarrying. It was from near the half-mile corner on the east side of section 30, that the block was taken for the state offering in the Washington Monument. (See p. 208.) The marble in the ledge from which the sample was taken is about four feet thick, has a light red color variegated with numerous white spots of fossil casts, and is of a homogeneous texture. Following is the analysis of a sample from this ledge:

Analysis of St. Joe marble from near Marble City.

	Per cent.
Lime (CaO)	55.390
Magnesia (MgO)	.190
Loss on ignition (CO_2 etc.)	43.740
Ferric oxide (Fe_2O_3)	.051
Alumina (Al_2O_3)	.009
Manganese oxide (MnO_2)	.015
Zinc oxide (ZnO) present, but not determined	......
Phosphoric acid (P_2O_5)	.023
Titanic oxide (TiO_2)	trace.
Insoluble residue (silica, etc.)	.800
Potash and soda (K_2O, Na_2O)	.054
Total	100.272
Calcium carbonate ($CaCO_3$)	98.710

NOTES: The hydrogen dioxide color test for titanium was obtained, but the usual test with tin and hydrochloric acid gave a doubtful result. Manganese

was calculated as manganese dioxide, but was not proven to be such. The insoluble residue was nearly colorless after digesting with dilute hydrochloric acid.

Along the tributary of Harp Creek which runs diagonally through section 30 (17 N., 20 W.), from the northwest to the southeast corner, the marble is exposed on both the hillsides and in the cedar glades in the northwest quarter of the section and through the north part of section 25 (17 N., 21 W.), appearing on the surface in slabs one to three inches thick, which are mostly firm and solid, variegated, dark red and pale green. Near the middle of section 30, the bed is 80 feet in thickness and is underlain by 40 feet of sandstone. The sandstone extends but a hundred yards above the big spring in the northeast of section 25 (17 N., 21 W.), where it dips beneath the marble. Above the spring the valley, which becomes much wider than in the lower part, is known locally as The Basin and contains broad exposures of the marble in the cedar glades. On the hills bordering The Basin, large quantities of crystalline gray limestone of the Boone chert are exposed, from which valuable building stone and some nice marble could be obtained.

In the southeast quarter of section 29 (17 N., 20 W.), on the east side of Mill Creek, the marble is 90 feet in thickness, and on the east side of the same hill on a tributary of Flat Rock it is 100 feet thick, the marble forming the top of the hill over an area of 20 or 30 acres, the upper layers being the crystalline gray limestone, the line between which and the red St. Joe marble cannot be clearly drawn, so imperceptibly do the two grade into each other.

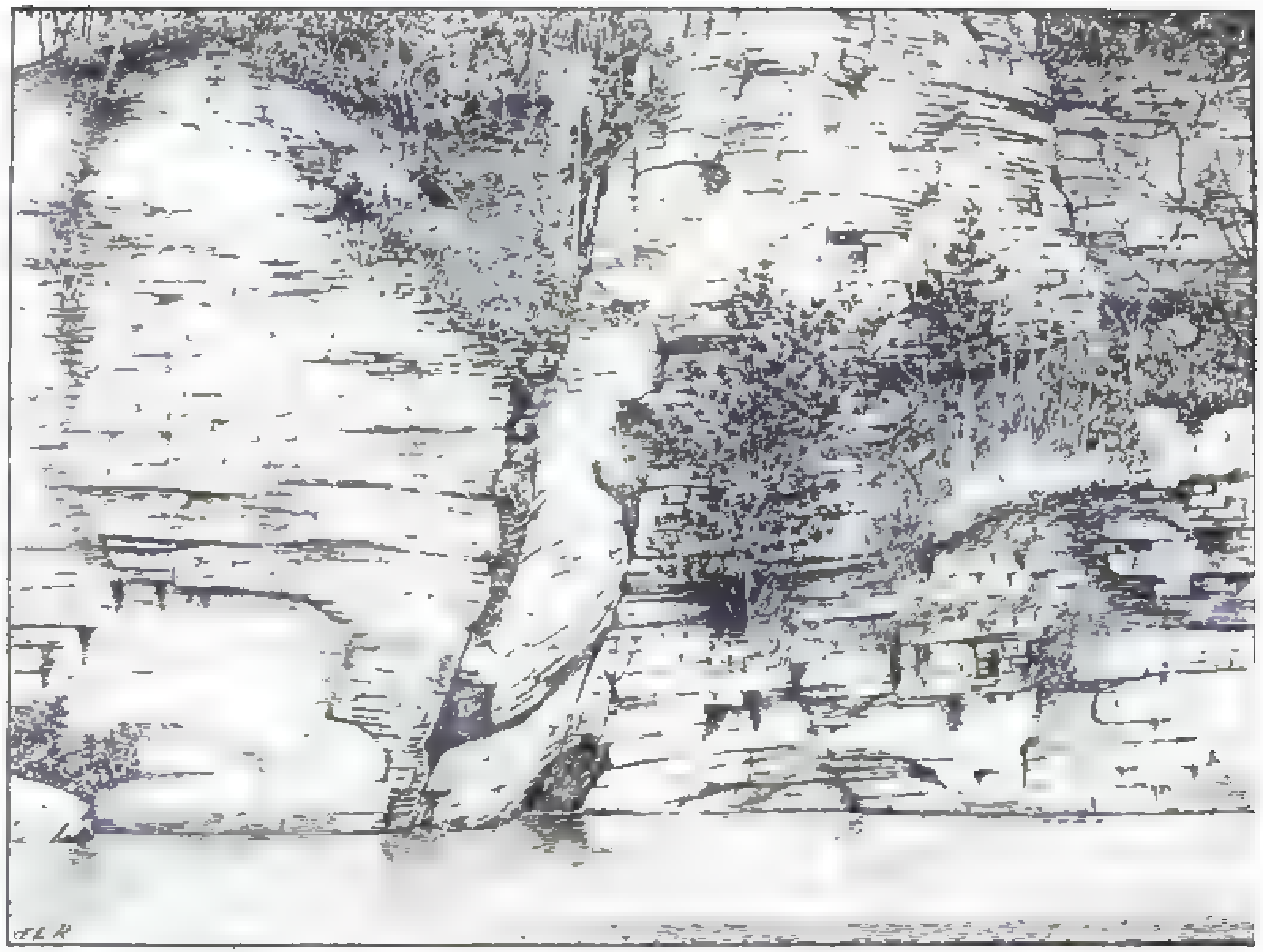
At Marble City in 17 N., 20 W., section 20, the south part, the marble is underlain by the saccharoidal sandstone, which extends from the village to the mouth of the creek in a bed varying from 50 to 100 feet in thickness. Between the sandstone and the marble are small local occurrences of a hard siliceous limestone and the Eureka shale. On the east side of the creek, opposite the blacksmith shop, the red marble is forty feet thick, near the base of which is a banded variety erroneously called lithographic, from which a handsome cabinet marble could be

obtained. On the surface exposure the greenish yellow bands are lines of weakness and less crystalline than the reddish brown body; however, this difference may disappear further from the surface. Overlying the red marble, the gray limestone and chert are 280 feet thick, of which the lower 90 feet are nearly free from chert. On the west side of the creek, in the village, the marble and limestone are exposed in larger quantities than on the east side. The red marble extends less than a quarter of a mile up the creek above the Bluff Spring.

The gray limestone extends up to the head of the creek, containing intercalary chert in some places, while in others it is exposed in a bed from 100 to 200 feet thick in layers from one to three feet thick, with no chert visible.

The facilities for working the marble in Mill Creek valley are excellent: its position being on or near the tops of the hills, with comparatively little chert to interfere; the underlying white sandstone forming wide shelves at the base of the marble on each side of the creek upon which good roads could easily be constructed; and there being a fine water-power where a never failing supply of water has a clear fall of 30 feet and where within a few yards a fall of 70 or 80 feet could be obtained. The chief drawback is the lack of railway or other transportation.

Between Mill Creek and Wells Creek.—At the mouth of Mill Creek the Silurian sandstones and siliceous limestones outcrop from the creek nearly to the top of the hill. But a dip of from five to ten degrees to the southeast carries them below the water-level less than a mile below the mouth of the creek, the change of level being further hastened by two small faults which have their downthrows on the south side. Thus in 16 N., 20 W., section 5, the south part, at the mouth of the ravine from the northeast, the marble is at the water-level. Fifty yards below the ravine is another fault with the downthrow on the north side. (See accompanying illustration—Plate XV.) On the south side of this fault from twenty to thirty feet of the Silurian rocks are again exposed, but less than a mile down-stream in section 8 (16 N., 20 W.), they are again below



FAULT ON BUFFALO RIVER SOUTH OF MARBLE CITY.

the water-level. In the southwest quarter of section 5 (16 N., 20 W.), on the south slope on the north side of the river between the mouth of the ravine and the mouth of Mill Creek, is a prominent outcrop of red and party-colored marbles in slabs and heavy layers. Below the mouth of the ravine, the exposed marble is more shelly and crumbling than that above it. On the south side of the river it is exposed in the bluff at the mouth of Mill Creek, but does not appear along the Marble City-Jasper road in section 8 (16 N., 20 W.). Near the middle of section 8, the marble horizon on both sides of the river dips beneath the water-level, the overlying chert forming the surface rock to near the mouth of Coots' Branch, in the southeast quarter of the section where the marble reappears; it outcrops a quarter of a mile or more up Coots' Branch, the strata in some places being broken and folded. Less than half a mile below the mouth of Coots' Branch in section 9 (16 N., 20 W.), the southwest quarter, on the hill below Mr. Henderson's, the marble is over 100 feet above the river, the Silurian rocks forming the base of the hill.

The marble extends up Fish Trap Hollow, along both sides, nearly two miles from the river, the upper limit being at the spring in section 3 (16 N., 20 W.).

About three quarters of a mile above the forks of Buffalo, River is a small tributary on the north side of Big Buffalo known as Boomer Mill Hollow, which contains some beautiful variegated marble. One variety, showing on the surface in slabs two to four inches thick, of purplish red color with olive-green patches, and slightly crinoidal, occurs at the base of the hill at the spring in the southeast quarter of section 3 (16 N., 20 W.); other varieties of the red marble occur along the hillsides between the spring and the river. Near the mouth of the creek the underlying white saccharoidal sandstone occurs in regular layers from two to eight inches thick, extending in broad sheets along the watercourse.

Wells Creek.—Wells Creek is the largest affluent from the north between Mill Creek and Davis Creek, and drains an area rich in marble. At the mouth of the stream the marble is

twenty-five feet thick and lies 100 feet above the river; it is exposed in the semicircular bluff on the east side of the small ravine just west of the mouth of the creek, but on the Wells Creek side of the hill and west of Wells Creek it is mostly concealed by the chert debris. The largest exposures between the mouth of the creek and the Wells Creek post-office are in a ravine in section 15 (16 N., 20 W.), the south part, on the north side of the creek, and in section 14, the south part, on the south side of the creek.

On the north branch of the creek, a quarter of a mile north of Wells Creek post-office, the marble is sixty feet above the creek and fifty feet thick, the heaviest layer visible on the surface being from two to three feet thick, with thin slabs one to three inches thick, both above and below it. One mile further north, in the northeast quarter of section 11 (16 N., 20 W.), the total thickness of the marble is nearly seventy feet, which includes one layer from fifteen to twenty-five feet thick of solid red encrinital marble, apparently without seams or flaws. The surface is weather-stained with a light greenish vegetable crust, but is firm and solid, and differs from much of the crinoidal marble in other places, in that the crinoid stems do not project; indeed, they cannot be seen on the weather-stained surface. The marble from this locality closely resembles the encrinital variety found at St. Joe, but the crinoid fossils do not occur so regularly, and a fresh broken surface, in a few places where it could be observed, more nearly resembles the Hawkins county marble of Tennessee; the white patches are more irregular than they are in the marble at St. Joe. This marble is in a good position for quarrying.

On the Pot Spring branch of Wells Creek, which joins the north branch at the post-office, the marble outcrop is almost continuous on both sides of the valley for nearly three miles. In Capps' Hollow, a ravine on the south side in sections 13 and 24 (16 N., 20 W.), the marble occurs in weathered ledges along the hillsides for half a mile, and in the bottom of the ravine and base of the hills for half a mile further. In the northeast quarter of section 24, in the red marble, is a large cave, the

roof of which is flat, and its sides perpendicular; the rocks show no signs of erosion except on the bottom. There is a similar cave on the main stream in 16 N., 19 W., section 18, the north part of the section, the roof of which is a slab of red marble forty yards across and nearly as smooth as a board ceiling; the floor of the cave is saccharoidal sandstone. Twenty yards up-stream from this cave are the noted Pot Springs, which occur in the creek bed in a siliceous limestone at the base of the marble; the name comes from the pot-holes formed in the limestone by the eddying water carrying chert fragments. The marble occurs along the creek nearly half a mile above the springs, where it disappears beneath the chert. Three quarters of a mile further up-stream a fault crosses this creek with the downthrow on the south, where the Batesville sandstone and Marshall shale are exposed, while on the north side the gray limestone of the chert series shows in large quantities.

Between Wells Creek and Davis Creek.—In the ravines in 16 N., 20 W., sections 36, 35, 34, and 27, small weathered outcrops of marble occur, the most conspicuous one being in section 26, the southeast quarter, at the spring near Mr. Christian's house, where a heavy ledge of red marble, full of cracks and seams, is exposed. A ledge of red marble outcrops near the top of the river bluff, west of the Big Creek road, in 15 N., 19 W., section 6, the northwest quarter, and in 15 N., 20 W., section 1, the northeast quarter.

The Gum Tavern Branch flows through a narrow rugged ravine, with the marble occurring near the top of the hill at the mouth of the stream, but at the base of the hill on the section line between sections 30 and 31 (16 N., 19 W.); it outcrops along the bottom of the ravine for nearly half a mile further upstream to a big spring. Along the hills below the spring are loose slabs from three to four inches thick, each containing from twenty to fifty square feet of marble and almost as regular as if they had been sawed. The marble bed in this ravine is fifty feet thick, overlain by fifty feet of disintegrating limestone.

The bottom of the marble is solid and regularly bedded, some of the strata being from three to eight feet in thickness.

The small tributary known as Bent's Hollow has marble exposed on the hills on each side for more than a mile from the mouth. A few boulders, crumbling and shaly, appear at Carver's mill, in the middle of the west part of section 29 (16 N., 19 W.), and a ledge fifteen to twenty feet thick, composed of thin slabs from two to four inches thick, outcrops on the south side of the ravine at the spring in the northwest quarter of the northwest quarter of the same section. Larger exposures occur near the top of the hill on the east side of the creek, but the surface of the rock is much disintegrated.

On the hill west of John Morris', in 16 N., 19 W., section 28, the west part, the east part of 29, and the northeast quarter of 32, from twenty to thirty acres of plain chocolate-red marble are uncovered; it has a maximum thickness of nearly 100 feet. It is much weathered, generally occurring on the surface in thin shaly slabs, but in the southwest quarter of section 28 there is one heavy ledge from three to eight feet thick of plain red, evenly bedded marble. For the first three miles along the north side of Buffalo River above Davis Creek, the Calciferous rocks extend from the water to near the top of the hill and are covered with chert debris, only mere traces of marble being exposed.

Davis Creek.—Davis Creek is a winding ramifying stream, draining the greater part of township 16 N., 19 W., the south part of 17 N., 19 W., and the northwest of 16 N., 18 W. The strata throughout the region drained by it are disturbed in many places, two faults crossing it in a nearly east and west direction, making the outcrop irregular and disconnected. The marble is at the level of the stream and in the base of the hills around the heads of the tributaries, but it occurs higher on the hillsides to the south, thus causing the underlying sandstone to appear in larger quantities nearer the river. On the east side of Davis Creek the first exposure of marble is nearly a mile from the river, while on the west side, the hill being higher, the marble horizon is not more than half a mile from the river;

but no marble is exposed, owing in large part to the disintegration of the rock and the concealment of the bed by the chert debris.

On the east side of Davis Creek, the marble first outcrops near the middle of the east part of section 23 (16 N., 19 W.), near the top of the hill, about 150 feet above the stream, and thence at intervals it appears through the chert to the mouth of Hurricane Branch, and along the east side of that tributary through section 14 to the southeast quarter of section 11, where there is a fault, which has an east-west direction and the downthrow on the north side, shifting the marble horizon from the hillside to the bottom of the creek, along which it outcrops for a quarter of a mile and then disappears beneath the chert. Half a mile northeast of the fault just mentioned, is another one with the uplift on the north side, causing the marble horizon to reappear on the hillside north of the creek. The outcrop brought to the surface by this fault extends along the north side of the creek through section 12 (16 N., 19 W.), across the county line, into and across section 7 (16 N. 18 W.), the hillside on the south side of the creek being covered with the Boone chert.

North of the middle of section 7 (16 N., 18 W.), is a bluff 100 feet high, with 25 feet of red marble at its base overlain by 75 feet of gray limestone, both being cherty and of an inferior quality. A cave occurs in the red marble north of Widow Martin's house at the base of the bluff.

The next tributary of Davis Creek, known as Still-house or Turney Hollow, is on the west side of the creek in the south part of section 15 (16 N., 19 W.). At Mr. Turney's house, in the north side of section 21, the marble outcrops in crumbling irregularly bedded layers, and for a quarter of a mile above the house it occurs along the base of the hills; down-stream from Turney's it is higher on the hillside, being from 100 to 150 feet above the stream at the mouth of the creek.

At the mouth of the tributary from the east at Mr. McDougal's, section 10, the southwest quarter, the red marble is near the base of the hills, while less than half a mile up the

creek it is in the creek bed and continues so for a quarter of a mile along the branch to the crossing of the fault in the northeast quarter of section 10, where, the uplift being on the north side, the position of the marble is changed to near the hilltop. Half a mile up-stream from the fault the stream divides and the red marble outcrops along both its branches. There is one persistent heavy ledge from three to six feet thick with thinner layers of the red crinoidal variety both above and below it, and from two to three feet of a crumbling gray marble underlying the red. Large quantities of marble are exposed in the ravines through sections 1, 2, and 11 (16 N., 19 W.).

Returning to Davis Creek proper, above Mr. McDougal's house in the west part of section 10, is a high bluff with the white Silurian sandstone forming the base and the red marble overlying it, covered with gray limestone and chert; all of which are much weathered, shaly, and crumbling. Above this bluff the creek makes a big bend to the southwest, at the upper end of which a fault (probably being the continuation of the one on McDougal branch, and having its uplift on the north side), crosses the stream, changing the marble horizon from the bottom of the hill on the south side to the top of the hill on the north side of the fault. On the west side of the creek, south of the fault, is a ravine from the east part of section 8, emptying into Davis Creek in the southeast quarter of section 9, around the head of which large quantities of red marble are exposed. Mr. Jones, who lives here, has worked considerable quantities of it into tombstones, which may be seen in many of the neighboring graveyards. He says he has worked both the Vermont and the Italian marble with this native marble, and finds the last to work easier and to take a finer polish than either of the others.

Immediately north of the fault above mentioned, there is no marble close to the creek, but it occurs on the hills about three quarters of a mile from the creek. The rocks have a north dip of 10° to 20° in some places, so that the marble which is near the top of the hill at the fault is at the creek level at Yardell in the north part of section 4 (16 N., 19 W.).

From the forks of the creek at Yardell the marble extends along the northeast branch nearly to Mr. Pope's house, in 17 N., 19 W., the east part of section 34; a distance of one mile. Occasional outcrops may be seen for a quarter of a mile further north on the tributary west of Mr. Pope's. It is in the north part of section 4, and the south part of section 34, in the cedar glades, that the largest outcrop occurs. A ledge from two to three feet thick, but with many seams on the surface, occurs opposite Mr. Mayberry's, in the northeast quarter of section 4 (16 N., 19 W.), while up-stream from this place all that shows on the surface is in thin irregular slabs, some of which are beautifully variegated with greenish gray spots in a purplish ground. It is possible that this slab form is wholly due to the weathering influences, and that heavier layers may be found beneath the surface.

On the northwest branch of the creek above Yardell, the rocks dip in various directions. Immediately west of Yardell the dip is east from 10° to 20°, thus giving a large marble exposure on the east side of the creek, with an outcropping of the underlying sandstone on the west side. In 17 N., 19 W., section 33, in the south part of the section, the marble dips beneath the surface to reappear 300 yards further up-stream. On the east side of the creek in the southwest quarter of this section (33) is a bluff eighty-five feet high, with the red marble in the base and the gray limestone overlying it. There is a large grotto in the face of this bluff containing some very pretty calcite formations; it is in the gray limestone, and the red marble forms the floor. The white sandstone which underlies the red marble appears at the upper end of this bluff and outcrops along the creek banks as far as Mr. Moore's house, at the foot of Boat Mountain, in the northwest quarter of the section. Some heavy ledges of the solid red marble are exposed along the east side of the creek, where the outcrop is much larger than on the west side.

Mt. Hersey Creek.—The tributary of Buffalo River from the north, and next below Davis Creek, is Mt. Hersey Creek. It enters Buffalo in 16 N., 19 W., section 25, and is about three

miles in length, very ramifying, and has large exposures of the marble and sandstone along its course. The first marble appears high on the hills nearly a mile from the river north of Mt. Hersey, and thence the outcrop is almost continuous up to the heads of the numerous ravines. The road from Mt. Hersey to the Harrison-Marshall road runs by one of the finest outcrops in the valley, in 16 N., 18 W., in the middle of section 18, the marble forming the sides and top of the low hill east of the road. Two or three acres of marble are exposed in this low gap, both north and south from which the ridge is covered with chert. At the bottom of the outcrop is a ledge of dark red marble, thirty inches thick, which is hard and full of surface flaws, overlying which are several layers but three inches thick, and irregularly bedded, overlain by evenly bedded solid layers from one to three feet thick, which vary in color, one being rose-tinted, and another beautiful variety red and very crinoidal; one layer from six to eight inches thick, is highly crystalline, light gray in color, and quite solid and firm, with the exception of a suture near the middle. A quarry could be opened here at little expense, and surface indications promise an abundance of good stone. At the steam mill, in 16 N., 18 W., section 18, the southeast corner, near the head of another ravine is a weathered outcrop of the red marble, inferior in quality to the one above mentioned.

Caney Creek.—At the mouth of Caney Creek in 16 N., 18 W., section 31, the southeast quarter, is a large exposure of the Silurian rocks which extend from the water's edge to the tops of the hills, the marble, which is much decayed, outcropping in places through the chert debris near the summit. The largest exposure observed on this stream is at the head of a short ravine on the east side of the creek in section 32, the east part, and in section 33, the northwest quarter, where it occurs in thin strata. The northern limit of the marble on Caney Creek is at the fault on the section line between sections 8 and 17 (16 N., 18 W.), where the downthrow on the north side cuts off the marble abruptly. The Boone chert in the creek bed on the north side of the fault abuts directly

against the saccharoidal sandstone on the south side of the fault. The red marble overlying the sandstone is forty feet above the creek at the fault; down-stream it is higher on the hills, owing to the deeper erosion of the creek. At the fault the marble outcrops in layers from one to three inches thick; half a mile south of the fault some of the layers are from two to three feet thick, but are full of seams.

Along the north side of Buffalo River the chert covers the hillside for two miles from the mouth of Jimison's Creek to the bluff in 15 N., 18 W., section 4, where the marble appears underlain by Izard limestone. In the small tributary at the west end of this bluff the marble is more than 100 feet above the base of the hill.

Jimison's Creek.—A monocline, similar to the one at St. Joe, crosses the eastern branch of Jimison's Creek in 16 N., 18 W., section 26, the southwest quarter, and the western branch in section 35, the northwest quarter. The dip at the monocline is to the south and causes the marble to disappear beneath the Boone chert which covers the valley and hills between the monocline and the river. North of the monocline the marble, underlain by the Calciferous rocks, appears on both branches of Jimison's Creek; these outcrops are separated from each other and from all other marble exposures, as they are entirely surrounded by chert. The outcrop is irregular and the chert debris covers the marble in many places. The topography along the north branch through section 26 is very rugged and the ravine is almost impassable, but above this in section 23, the east side, and section 24, the west side, the valley is wider and the hills less precipitous. The lower part of the marble bed on Jimison's Creek is composed of St. Clair marble, while the upper part is St. Joe.

CHAPTER XXI.

DISTRIBUTION OF THE ST. JOE MARBLE—*Continued.*

NORTH SIDE OF BUFFALO RIVER VALLEY, BELOW JIMISON'S CREEK.

(Harrison map sheet.)

Mill Creek, Searcy county (*St. Joe region*).—The Mill Creek valley has some interesting structural geology, the details of which cannot be shown on the map. The monocline and the two faults north of St. Joe cause a great many different strata to outcrop and the outcrop of any one stratum to appear at many different levels. The Boone chert outcrops from the mouth of the creek to the outskirts of the village of St. Joe, at which place, and over several square miles east and northeast of the village, the overlying Batesville sandstone and Marshall shale are the surface rocks. The sandstone also occurs on the ridge west of Mill Creek; the extent of the exposure is shown on the map. North of the village are exposed the shale, sandstone, Boone chert, St. Joe marble, Sylamore sandstone, St. Clair marble, Izard limestone, the saccharoidal sandstone, and the siliceous magnesian limestones, all within the space of a square mile. The folded and dislocated condition of the strata is shown in the accompanying illustration (Fig. 5).

The lowest exposure of the St. Joe marble on Mill Creek is in 16 N., 17 W., section 17, the northwest quarter of the northwest quarter, about three quarters of a mile north of the village of St. Joe. The outcrops at this place are all on the St. Joe monocline on both sides of the creek; the dip is southeast, varying from 10° to 20°. North of the monocline the strata change, within a few hundred feet, to a nearly horizontal position. On the bluff on the north side of the creek 200 yards above, the St. Joe marble is 30 feet above the creek and

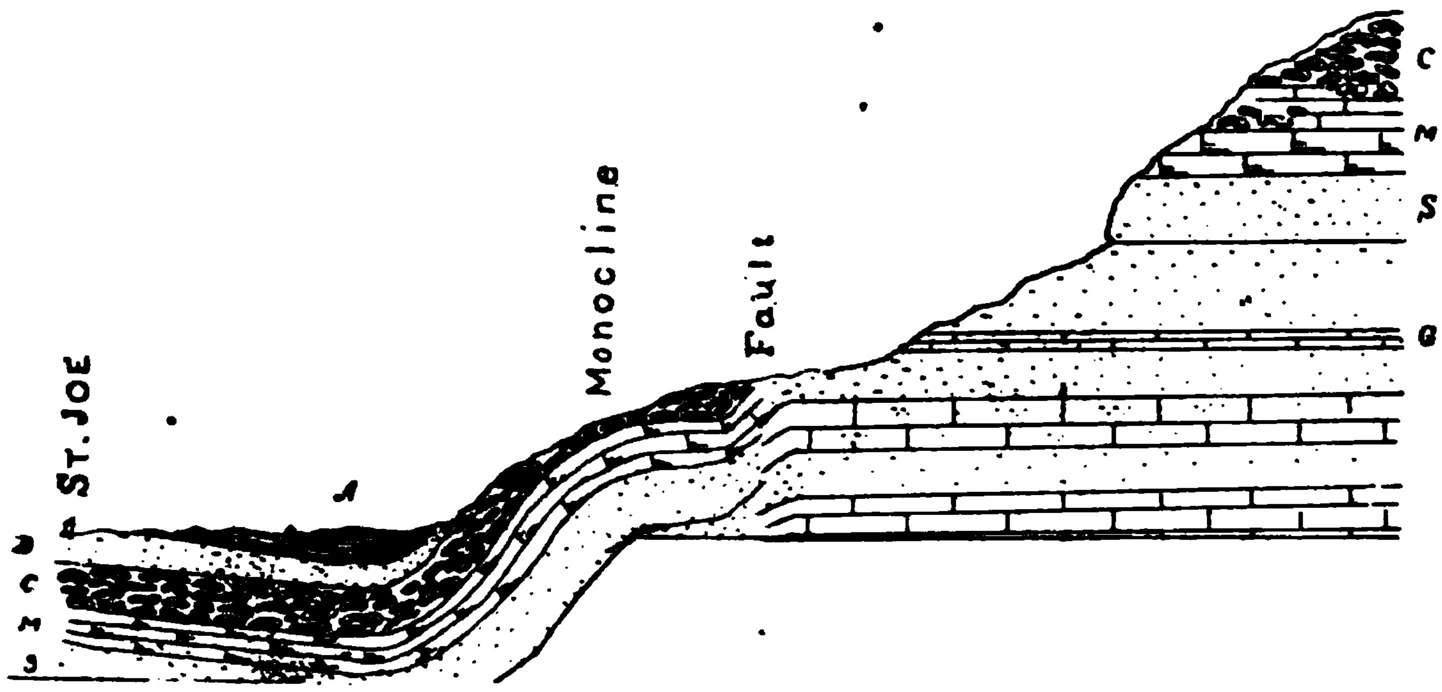


FIG. 5. *Monocline and fault at St. Joe.*

A, Marshall shale.
B, Batesville sandstone.
C, Boone chert.
M, St. Joe and St. Clair marbles.
S, Saccharoidal sandstone.
G, Calciferous rocks.

is underlain by the St. Clair marble from which it is separated by a layer of Sylamore sandstone two or three inches thick. In and below the bluff, the surface marble (St. Joe) is in thin shelly layers with numerous seams of amorphous material. On the ridge north of the creek, on the point of the hill between Monkey Run* and Mill Creek, some beautiful varieties of the St. Joe marble are exposed, the handsomest being the white spotted encrinital variety, which occurs in ledges three or four feet thick. Between this and the St. Clair marble is a bed of chocolate colored, homogeneous, finely crystalline marble, occurring on the surface in layers from two to ten inches thick. The Arkansas Marble Company took out some specimens of the encrinital variety for exhibition in Little Rock and elsewhere, and in doing so penetrated four or five feet below the surface, at which point the seams almost entirely disappear and the color is lighter than at the surface. No opening has been made in the other layers. As shown in the following results the fossiliferous variety has a lower specific gravity and crushing strength than the non-fossiliferous and single colored variety:

*Monkey Run is the name given to the small tributary entering Mill Creek from the north, one mile northwest of the village of St. Joe. The name is sometimes applied to Mill Creek and sometimes to the village of St. Joe.

Specific gravity and crushing strength of St. Joe marble from St. Joe.

	Specific gravity.	Crushing strength in lbs. per sq. in.
Encrinital marble......................	2.7072	11,265.4
Encrinital marble......................	2.6972	10,447.4
Chocolate colored marble	2.7120	17,835.2

These results* show both varieties to be above the average strength for marbles and far in excess of any strength which will ever be required of them.

Chemical analysis of the encrinital marble, taken from the quarry at this place, shows it to contain 98.73 per cent. of carbonate of lime and 1.16 per cent. of insoluble residue, the residue consisting mostly of iron oxide and silica.†

The marble on the point of the hill between Monkey Run and South Mill Creek lies in good position for quarrying, and there are several varieties of it. The succession of rocks at this locality is: Izard limestone at the creek, overlain by light pink St. Clair marble, then St. Joe marble (light red, chocolate, variegated white and red, and gray), and Boone chert at the top of the hill. An eighth of a mile north of the junction of Mill Creek and Monkey Run, the St. Joe fault, which runs east and west and has its downthrow on the south side, changes the marble horizon, carrying it up to the hilltops 180 feet higher on the north side. Less than half a mile west of the mouth of Monkey Run, the Mill Creek fault on the south side of the stream strikes east-west and, having its downthrow on the north, changes the level of the marble horizon 100 feet higher along the south side of Mill Creek for about two miles. Thus the two faults as shown in Fig. 6 cause three separate out-

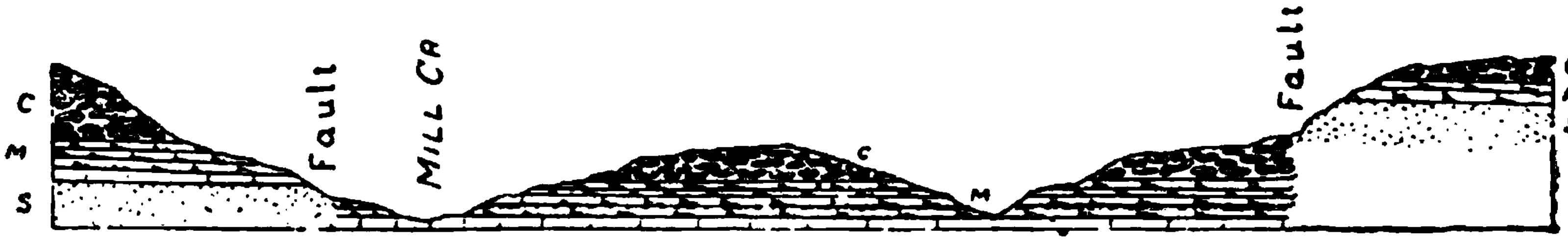


FIG. 6—*Faults on Mill Creek, west of St. Joe.*
C, Boone chert. M, St. Joe marble. S, Saccharoidal sandstone.

*For further details and comparison, see Chapter XIX.

†See table on p. 211 for comparison. For analysis and description of the St. Clair marble at this locality, see pp. 217 and 253.

crops of marble on Mill Creek west of its confluence with Monkey Run: (1) a continuation of the one partly described which continues along the base of the hills close to and in the creek for a mile or more into 16 N., 18 W., section 13, where it is succeeded by the overlying chert; (2) an outcrop along the south side of Mill Creek, on the south side of the fault, where the marble is 150 feet above the creek in the middle of section 18 (16 N., 17 W.), but at a gradually lower level up-stream until it is not more than 50 feet above the creek at the western limit of the exposure in 16 N., 18 W., section 14; (3) the exposure which occurs north of the north fault and which extends from 16 N., 18 W., section 11, around the heads of the small tributaries entering Mill Creek from the north, and the numerous branching ravines of Monkey Run and Turney Branch, to 16 N., 17 W., section 9, the northwest quarter. The finest surface exposures along this line are in section 7 (16 N., 17 W.), the northeast quarter, on a tributary of Monkey Run, and in the southwest quarter of the same section on the north side of Mill Creek valley.*

Tomahawk Creek.—Judging from surface indications, there is no St. Joe marble of commercial importance along Buffalo River, between Mill Creek and Tomahawk Creek, however, the marble is exposed on Dry Creek, 16 N., 16 W., section 30, and in the river bluff in section 21 (16 N., 16 W.), the south part.

The outcrop along Tomahawk Creek is very irregular and disconnected, owing to faults and folds in the strata. The St. Joe marble outcrops in large quantities around the head ravines and in smaller quantities at the mouth of the creek, while along the middle course of the creek it outcrops on the hill, a mile or more north of the stream, and in several small areas along its bed. In 16 N., 17 W., sections 2 and 11, the strata are exposed from the Silurian to the Millstone grit in the following order, beginning at the base: siliceous and magnesian limestones; saccharoidal sandstone; St. Joe marble; Boone chert, consisting mostly of limestone; Batesville sandstone; Marshall

*See chapter on Faults and chapter XIX. for further details on this area.

shale; the Millstone grit, with possibly intervening beds concealed between the last two. Two miles down the creek the St. Clair marble and Sylamore sandstone are exposed.

At the mouth of the creek is a small exposure of Silurian rocks, with the marble close to the creek level. In 16 N., 16 W., section 21, the northeast quarter, on the south side of the creek and less than a quarter of a mile from its mouth, is an exposure of both the St. Clair and St. Joe marble, in which there is a solid bed of St. Joe, twenty feet or more in thickness, with a thinly laminated bed overlying it.

At the mouth of Mud Spring Creek, a small tributary entering Tomahawk Creek from the north, the marble occurs in the bottom of the watercourse as far as the fault in section 16 (16 N., 16 W.), the southeast quarter. The downthrow of this fault is on the south side, and the marble horizon to the north of the fault is changed to near the top of the hill, the displacement being about 150 feet. A section across the fault on the east side of Mud Spring Creek, in the narrow ridge between this stream and the river, is shown in the chapter on Faults. The St. Clair marble shown in the figure has a thickness of twenty feet on the river side, but does not occur on the Mud Creek side of the hill. North of the fault the marble outcrops on each side of the creek to near the middle of section 10 (16 N., 16 W.). In section 15, the northwest quarter, the marble is underlain by a bed of blue Izard limestone, which disappears in section 10, the southwest quarter, where the marble is underlain by saccharoidal sandstone, in which the creek has worn a deep, narrow gully. On the top of the sandstone, at the base of the marble, there emerge in a soft clayey soil, several small springs, from which the stream takes its name.

On the main stream (Tomahawk Creek) the marble outcrops for a quarter of a mile above the mouth of Mud Spring tributary, and then dips beneath the overlying chert, reappearing at intervals through sections 17 and 18 (16 N., 16 W.). There is a small outcrop on the creek bank, both above and below the Needmore mill, in 16 N., 17 W., section 12, above which it does not appear again until the fault is passed at Mr. Gains'

spring, in 16 N., 17 W., section 2. At the fault the marble is below the water-level on the south side, but on the north side it is 180 feet above the bed of the stream. The displacement by this fault is not less than 200 feet.

The marble outcrops along the north side of the fault in a nearly east direction through section 1 (16 N., 17 W.), and sections 6, 7, and 5 (16 N., 16 W.). In section 1 (16 N., 17 W.), the northwest quarter of the southwest quarter, is a fine outcrop of the chocolate colored marble which appears to be homogeneous both in color and texture; it occurs in slabs from two to six inches thick, while the total thickness exposed is about 25 feet, with part of it concealed by the chert debris. It has been quarried to some extent for local use, and is admirably located for quarrying. Its composition shows it to contain more impurities than that at St. Joe, but the impurities are such as would not injure its use for either ornamental or structural purposes.

Analysis of chocolate colored marble from 16 N., 17 W., section 1.

	Per cent.
Silica (SiO_2)	2.43
Alumina (Al_2O_3)	0.36
Ferric oxide (Fe_2O_3)	1.05
Manganese oxide (MnO_2)	trace
Lime (CaO)	53.46
Magnesia (MgO)	0.46
Potash (K_2O)	0.16
Soda (Na_2O)	0.16
Loss on ignition (carbon dioxide and volatile matter)	42.30
Total	100.38
Water at 110°-115° C	0.10
Lime carbonate ($CaCO_3$)	95.45
Specific gravity	2.6744
Weight per cubic foot	167.05

It outcrops at Mr. Thompson's spring, section 1 (16 N., 17 W.), the southwest quarter; at Mr. William Keeling's spring in the southeast quarter of the same section; at the copper mine in section 6 (16 N., 16 W.), southwest quarter; in the ra-

vine east of the smelter in section 7, the northeast quarter; on the ridge in section 8, the northwest quarter; around the head of the ravine in section 5, southwest quarter; and probably in places to the southeast through sections 8 and 9 towards the mouth of the creek.

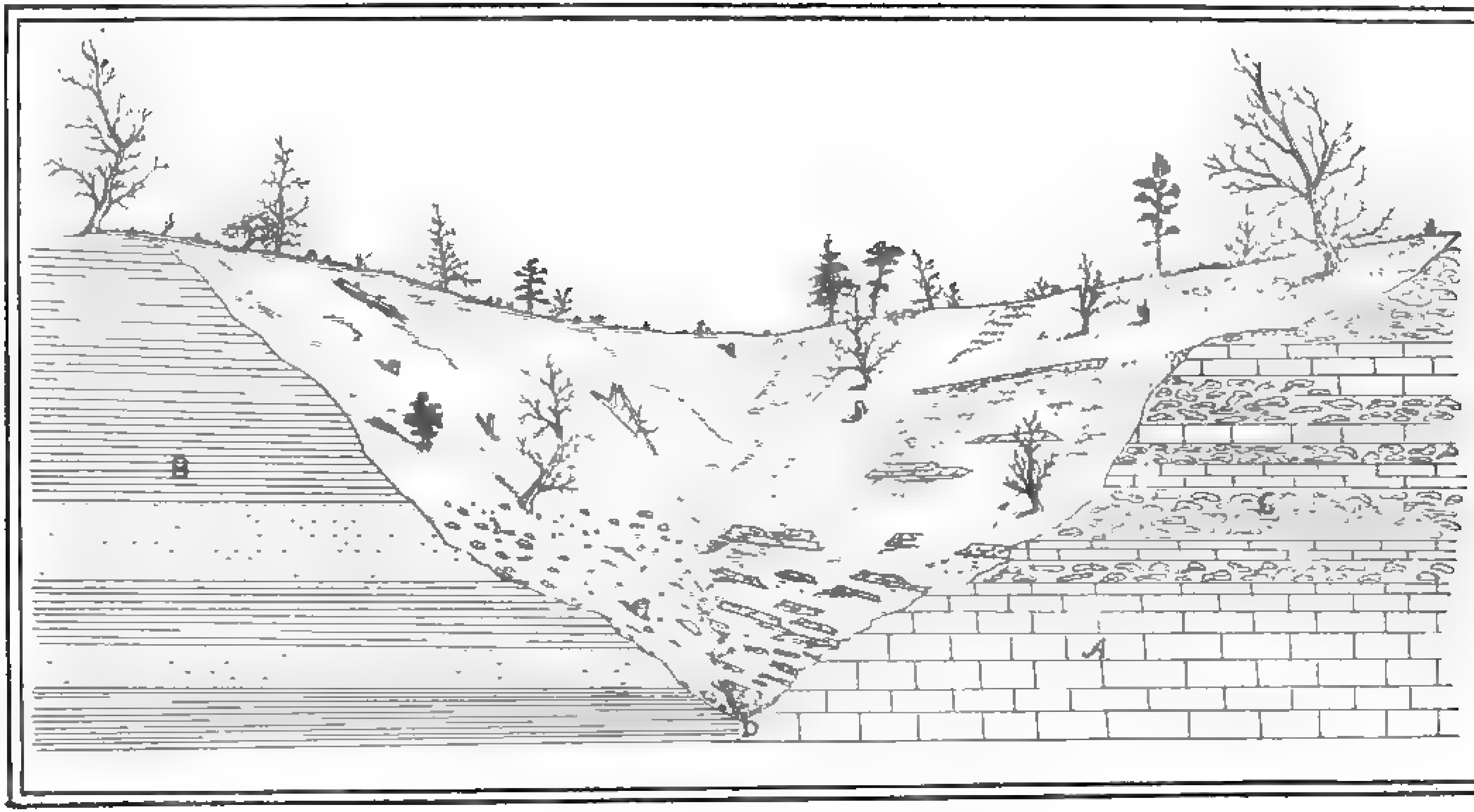
The accompanying illustration (Plate XVI.) shows a section across the fault at the mouth of the ravine near Mr. Parks' house in 16 N., 16 W., section 8. The line of fault corresponds closely with the bottom of the watercourse.

North from Gains' spring along Tomahawk Creek the strata have a north dip of 5°, which brings the marble horizon nearly to the creek level on the north side of section 2 (16 N., 17 W.). It outcrops on both sides of Eureka Hollow in large quantities, the finest exposures being in the small ravine on the south side of the hollow.

A quarter of a mile above the mouth of Eureka Hollow is another tributary on the same side of the creek, known as Pine Hollow; in this the marble outcrop is similar to that in Eureka Hollow except that it is nearer the base of the hills. The underlying saccharoidal sandstone outcrops at the mouth of the hollow and extends up it about 100 yards, where it disappears, the marble outcropping along the bottom of the eastern branch from a half to three quarters of a mile further. A fault crosses the stream from the northeast in 17 N., 17 W., section 36, the west side, with the downthrow on the south side; this shifts the marble horizon from the bottom of the ravine south of the fault to near the top of the hill north of the fault, and from this line the marble extends around the head of the ravine.

A fault, which is a continuation of the one mentioned above, crosses Tomahawk Creek 100 yards above the mouth of Pine Hollow, where, as in the one mentioned, the marble horizon is changed from the bottom of the hill on the south side to near the top on the north side. A section across this fault is shown in the chapter on Faults.

Half a mile up Tomahawk Creek, from the mouth of Pine Hollow, is a large tributary from the west, known as South Prong of Tomahawk, on the north side of which are numerous



FAULT IN 16 N., 16 W., SECTION 8, LOOKING WEST OF NORTH.

A St. Joe Marble. *B* Marshall Shale and Sandstone. *C* Boone Chert. *D* Line of Fault.

and extensive outcrops of marble, while on the south side but one exposure has been observed, and that is near the head of the creek, in 16 N., 17 W., section 6, the southeast quarter. The abundant outcropping of the marble on one side of the valley and scarcely at all on the other, is not an uncommon occurrence through the marble area; as a rule the outcrops are larger and more numerous on hillsides facing south than on those facing north.

In 17 N., 17 W., section 28, on the southwest quarter, the marble contains numerous veins of specular iron ore an eighth of an inch or more in thickness, which, though not abundant enough on the surface to be of any value, are sufficient to injure the marble. An opening a foot or more in depth has been blasted in the rock, showing the veins in the interior to be of about the same size as at the surface, but they are more numerous.

On the hill north of Mr. Wall's, in 17 N., 17 W., section 29, the northwest quarter of the southwest quarter, a section shows:

Section on South Tomahawk Creek.

	Feet.
Boone chert	100
Gray crystalline limestone	40
Red St. Joe marble	50
Saccharoidal sandstone and limestone	20

The sandstone occurs in thin strata interstratified with siliceous limestone. The marble is in layers from one inch to three feet thick, the average thickness being from three to five inches, and some of the layers being firm and solid. It has been quarried for local use in chimney building. At the head of the ravine, northwest from Mr. Wall's, at the spring in section 30, the marble outcrops in a solid ledge at the base of the hill, where it is overlain by a heavy bed of gray limestone.

In section 32 (17 N., 17 W.), the southwest quarter, on Jack Younger's property, is an exposure of the marble at the top of a low hill, where four or five acres are uncovered. It occurs in layers from one to six inches thick, evenly bedded, firm and

strong, in places very crinoidal, the bed having a total thickness of 40 feet.

In 16 N., 17 W., section 6, the northeast quarter of the northeast quarter, on the east side of a small tributary from the north, the following section is exposed:

Section in 16 N., 17 W., section 6.

	Feet.
Boone chert	30
Gray limestone	80
Intercalary chert and limestone	41
Red St. Joe marble	60
Siliceous limestone (Silurian) / Saccharoidal sandstone / Siliceous limestone	40

The marble occurs in layers from one to six inches thick, and variegated in color, some layers being very fossiliferous. The gray limestone is in layers from two to four feet thick.

On North Tomahawk Creek, which unites with the South Prong in section 35 (17 N., 17 W.), the red marble outcrops on both sides of the main creek and in the numerous ravines. A section on the hill northeast of Mr. Adams', 17 N., 17 W., section 26, the southwest quarter, shows:

Section on North Tomahawk Creek.

	Feet.
Boone chert	25
Gray limestone	45
Red marble in slabs from 2 to 4 inches thick	25
Red marble containing intercalary chert	20
Red marble in solid ledge	10
Calciferous rocks—sandstone and limestone	130

Some of the red marble is plain chocolate colored, some variegated with light green patches, and some very crinoidal. The other more prominent exposures on this stream are as follows: in section 28 (17 N., 17 W.), the north part of the section; on the east side of the road north from Britt Harris'; and in section 22, near the middle of the section, on the hill northwest of Reuben Herrington's.

Buffalo, between Tomahawk and Water Creeks.—On Buffalo River, north side, the marble lies near the tops of the hills and

outcrops nearly all the way from the mouth of Tomahawk to the mouth of Water Creek. On the river bluff in 16 N., 16 W., section 12, the west part of the section, the marble is 40 feet thick, overlain by 20 feet of chert; it has 260 feet of Calciferous rocks showing below it, of which the first 50 feet are of the saccharoidal sandstone. In the northwest quarter of section 12, about half a mile north of the river on the east side of a short tributary, the red marble is 30 feet thick, is 60 feet lower than it is at the river, and of much better quality, the upper part of the bed being light colored and filled with fossil crinoid stems.

Water Creek.—The extensive exposure of the marble on Water Creek is due to the existence of faults within its basin which bring the marble bed to the surface, when without them this horizon would ordinarily be carried below the drainage level. Two faults cross the creek in a northeast-southwest direction, one in 17 N., 16 W., section 35, the other in section 30, in both of which the downthrow is on the southeast side. The marble is on the tops of the high hills at the mouth of the creek, but by a more or less regular descent it is at the base of the hill at the first fault five miles from its mouth. On the north side of the fault it is shifted to near the hilltop, but is again at the water-level on the south side of the next fault, nearly five miles further up-stream; on the north side of which the marble is again carried up to near the top of the hill. At the mouth of the creek the marble, lying as it does on the tops of the high hills, is much decayed so that but mere traces of it are visible for two miles or more from the river.

Two ravines on the north side, one in 16 N., 15 W., section 5, and the other in section 6, same township, named Bear Pen and Silver, contain large exposures of the St. Joe marble.

The next affluent of Water Creek west of Silver is called *Caney Creek*, at the mouth of which in 16 N., 16 W., section 1, north part, the marble is near the base of the hill and has a marked dip to the west, but there are many local folds up the creek with the rocks dipping in many different directions. A quarter of a mile from the mouth of Caney Creek on the east

side and below the mouth of a small ravine, is an overhanging ledge of red marble about 25 feet thick, underlain by a fine-grained blue limestone, much wrinkled and contorted. The bottom layers of this red marble have disintegrated and the debris has been carried away by the creek, while a number of the upper and more solid layers have fallen and large slabs from two to four inches thick, each containing 25 to 40 square feet of marble are scattered through the heaps. On the hillside west of this ledge the marble, which is much weathered, is 50 feet thick.

In the ravine on the east side of Caney Creek, at the upper end of the ledge referred to, large quantities of fine marble are exposed, some of which is now lying in large slabs and blocks waiting to be dressed. It is in this ravine that Mr. Somers of Sylva obtained much of the marble used by him for tombstone work. In the upper part of the ravine, 17 N., 16 W., section 36, the northeast quarter, and 17 N., 15 W., section 31, the northwest quarter, the marble forms a ledge from ten to twenty feet thick along the base of the hills on each side of the ravine; from five to ten feet of this ledge are apparently without seams or breaks of any kind, while the remainder is in slabs from two to six inches thick. The Survey did not examine either of the large branches of Caney Creek above this, but Mr. Somers of Sylva, who is familiar with the region, furnishes the information that the marble extends nearly to the head of all the ravines and that the saccharoidal sandstone forms a high, con-conspicuous ledge along the main tributaries.

Between Caney Creek and *White Oak Branch*, a little more than a mile, the marble lies near the base of the hills and outcrops in heavy layers from two to six feet in thickness. The fault which crosses Water Creek, at the mouth of White Oak Branch, changes the level of the marble from the creek bed to near the tops of the hills. In this position it outcrops with little variation along both branches of White Oak, the Calciferous rocks, in bluffs or rugged slopes, forming the base of the hills for a distance of from 100 to 150 feet, the marble in rounded boulders and weathered ledges overlying this, with chert covering

the hillsides. In many places, however, the marble is covered with the broken chert, and does not appear on the surface. In the small ravine which opens on the west side of White Oak near its mouth, in the northwest quarter of section 35 (17 N., 16 W.), and the southwest quarter of section 26, is a fine ledge of the red marble exposed on the east side and around the head of the ravine, while on the west hillside it is covered with the broken chert. Both the red and variegated occur at this place in layers from six inches to six feet in thickness, underlain by the saccharoidal sandstone.

On the north side of Water Creek, between White Oak and Barren Fork, in the northwest quarter of section 35 (17 N., 16 W.), near the top of the hill, there is a fine exposure of marble, underlain by blue limestone and capped with chert. The prevailing colors are chocolate and variegated, the latter consisting of large, irregular light green patches in dark red. On the south side of the creek, in the southwest quarter of section 35 (17 N., 16 W.), the hill is very steep, almost a bluff, the marble being 140 feet above the creek and mostly concealed by the overlying chert.

The next affluent of Water Creek above White Oak is called *Barren Fork;* it has two large branches, along both of which marble is exposed. At the mouth of Barren Fork the marble is near the top of the hill, but it is mostly concealed by the chert debris. On the more southern branch, in section 20, the northeast quarter, the marble, which is both red and variegated, occurs in large quantities at the base of the hill on the south side of the fault; while on the north side of the fault are the magnesian limestones and sandstones, the marble reappearing near the tops of the hills at the heads of the numerous ravines, 200 to 250 feet higher than on the south side of the fault and a mile or more to the northwest. At the head of the northern branch of Barren Fork, on the north side of the fault in section 9 (17 N., 16 W.), the northwest quarter, is a conspicuous outcrop of the red marble and the gray limestone, both occurring in massive crystalline and fossiliferous ledges.

On Water Creek above the mouth of Barren Fork, the

marble outcrops in irregular patches on both sides of the stream. In a small ravine which drains toward the east from Mr. Still's house, through the south part of section 32 (17 N., 16 W.), the red and variegated marbles of fine quality outcrop in heavy ledges, which include some of the most compact, highly crystalline marbles along Water Creek. Near the middle of the west side of section 33 (17 N., 16 W.), on the hillside east of Water Creek, is a cave in the red marble, where a section on the hillside shows 10 feet of saccharoidal sandstone at the base, overlain by 30 feet of compact blue limestone, followed by 35 feet of red marble, and 50 to 100 feet of Boone chert at the top.

A quarter of a mile up-stream from the cave, near the section line between 32 and 33 (17 N., 16 W.), on the north side of the stream, and 200 yards west of the Marshall-Yellville road, is a remarkably fine display of marble; a section on the hill at this point shows 40 feet of blue limestone at the bottom, 60 feet of red and variegated marble, one to two feet of chert, 50 feet of gray limestone, and one to ten feet of very fossiliferous chert at the top. Near the bottom of the bed of red marble are some handsomely variegated slabs, some of the upper layers being very crinoidal, and a few layers being of the smooth-grained, rose-tinted variety. It occurs in layers from two inches to two feet thick, averaging sbout five inches, and has a south dip of from 5° to 10°.

In the northeast quarter of section 32 (17 N., 16 W.), Water Creek divides; its northern branch is called *Taylor Fork*, and along this the marble occurs at the base of the hills for nearly two miles up-stream from the place where it enters Water Creek, or as far as the fault in section 19 (17 N., 16 W.), the southeast quarter. Northwest of this fault the marble shifts to the tops of the hills; for more than a mile no marble at all occurs on the north side of the stream and but little on the south side. Further up-stream, however, in 17 N., 17 W., sections 13 and 24, are some fine outcrops. On the east side of section 24, north and east of Frank Taylor's house, is a large exposure of

much weathered, shaly, crumbling marble, but west through section 24 the quality improves.

On Haw Hill, in the southwest quarter of section 24 (17 N., 17 W.), is an outcrop of red and gray marble which has acquired quite a local reputation, as persons come here from long distances for marble to build chimneys and for tombstones. An area of eight acres or more of the marble is exposed with no covering, the upper 10 to 15 feet being gray, crystalline, firm and compact to the edge, and covering the surface in large boulders from 2 to 10 feet in diameter. Underlying the gray marble is the red and variegated St. Joe bed, which is also firm and compact, the loose slabs giving a clear metallic ring under the hammer. It occurs in layers from one inch to three feet in thickness, averaging about five inches. On the north side of Taylor Fork, in the northwest quarter of section 24 (17 N., 17 W.), is a somewhat similar but smaller exposure, and, so far as can be judged from surface indications, inferior in quality to that at Haw Hill.

On another tributary of Taylor Fork, in the south part of section 13 (17 N., 17 W.), west from Mr. Harris's, the marble outcrops in large quantities.

On the *southern branch of Water Creek* from the fork in 17 N., 16 W., section 32, the northeast quarter, the marble exposure is similar to that on Taylor Fork, but is less extensive and not of such fine quality as that on Haw Hill. In the northeast quarter of section 32 (17 N., 16 W.), is a local syncline where the marble horizon dips beneath the water-level for about 100 yards; west of this through the northwest quarter of section 32, the marble reappears along the hillside underlain by a heavy bed of saccharoidal sandstone in which the creek has cut a deep, narrow gorge. The western limit of this sandstone is at the cataract in section 31, the northeast quarter. Through the northeast quarter of section 31 and the southeast quarter of section 30 the marble occurs along the base of the hills nearly to the fault at the section line in the southwest quarter of section 30 (17 N., 16 W.), where, the uplift being on the west side, the marble horizon is changed to near the top of the

hill, and it thus continues to the head of the stream, covered in many places with broken chert.

In the region about the heads of Water Creek, Tomahawk Creek, and Hampton Creek, it will be noticed that the marble lies close to or on the tops of the hills, thus causing larger areas to be exposed than where it occurs along the base of the hills.

Saltpeter Hollow and Jim Hollow.—In the two small tributaries of Buffalo River in 17 N., 15 W., sections 32 and 33, known locally as Saltpeter Hollow and Jim Hollow, the marble outcrops near the tops of the hills. In the northern part of section 34 it occurs at a much lower level and both the St. Joe and St. Clair marbles are exposed with a dip of several degrees to the east. A fine ledge of the St. Joe marble is exposed in the river bluff in section 27 (17 N., 15 W.).

Panther Creek.—The St. Joe marble occurs on nearly all the ramifying branches of Panther Creek, the finest outcrop observed being in 17 N., 15 W., section 16, the southeast quarter, on a small tributary entering Little Panther from the northeast. At Sylva post-office on the head of Panther Creek, section 20 (17 N., 15 W.), the northwest quarter, it appears through the chert debris in irregular ledges with a loose fissile structure. Mr. Somers, the postmaster, has found some slabs here suitable for tombstone work, yet most of the stone he used was obtained from other localities in the neighborhood. Between the mouth of Panther Creek and Rush Creek the red marble is exposed the greater part of the way, noticeably on the bluff in 17 N., 15 W., section 15, the southeast quarter, and in section 23, the northwest quarter.

Rush Creek.—The geologic structure on Rush Creek differs from that on Water and Tomahawk Creeks, in that the latter creeks cross the faults at nearly right angles, while Rush Creek for a considerable part of its length runs along a line of fault, which is nearly at right angles with the direction of the great fault on the other creeks. The downthrow of the Rush Creek fault is on the southwest side, where there is an extensive outcrop of marble, while on the northeast side of the fault, the

underlying Silurian rocks extend nearly to the hilltop, only a small area east of Rush post-office being capped with marble and chert. Between the post-office and the mouth of the creek on the south side of the stream the strata have a marked dip to the northwest, so that the St. Joe marble, which is 260 feet above the water at the mouth of the creek, is only 50 feet above the creek at the post-office, above which it occurs at different levels owing to gentle folds in the strata. In the ravine opposite the post-office the rocks also have a dip north of east towards the creek.* Two hundred yards west of the post-office at the crossing of the Clabber Creek-Sylva road the marble horizon is concealed by the chert debris, but it outcrops a short distance west of the road, and in all the ravines entering Rush Creek from the south side.

At the mouth of Cove Creek, a short tributary in section 4, (17 N., 15 W.), the southwest quarter, the marble horizon is 140 feet above the water-level, and on the small tributary east of the forks of the creek, in the eastern part of section 6, it is 150 feet above the water and 30 feet higher than on Cove Creek. The quality of the marble in section 6 appears to be better than at any point between this and the mouth of the stream.

In section 5 (17 N., 15 W.), the northwest quarter, two branches of Rush Creek unite; on the right or northern branch the marble outcrops along the south side close to the water, and in the small ravine in section 6 (17 N., 15 W.), northwest quarter, it is only ten feet above the stream. It is exposed in thin weathered ledges through 17 N., 16 W., section 1, the north part of the section, and through the northeast quarter of section 2, as far as the head of Mill Creek in the Crooked Creek basin.

The other and larger branch of Rush Creek from the west and southwest, locally known as Cold Water branch, crosses the Rush Creek fault a little over a quarter of a mile above the junction; above the fault the marble outcrop is almost con-

*See chapter on Faults for figure, showing section across Rush Creek at the post-office.

tinuous on both sides of the stream, but it is covered in a few places with the chert debris. It is of finer quality than on the lower part of Rush Creek, and has a deep brownish red color, which it has imparted to the soil and underlying rocks. In 17 N., 16 W., section 12, the north part, at the double springs, the marble is 100 feet above the base of the hill, and in the north-east quarter of section 11 it is only fifty feet from the base of the hill. Through the south part of section 2 it appears on the north side of the creek in a solid ledge from fifteen to twenty feet thick, overlying a heavy bed of the saccharoidal sandstone. In the southwest quarter of section 2 is a ravine from the north, flowing through the west part of this section, in which is a large exposure of the marble. Near the head of the ravine in the northwest quarter of section 2 the red marble is forty feet in thickness, overlain by ninety feet of the gray limestone, which covers the surface in large boulders from three to ten feet thick.

In section 3 (17 N., 16 W.), the southeast quarter, is another ravine from the north, half a mile west of the one above mentioned; along this ravine but little marble is exposed, the Calciferous rocks extending nearly to the tops of the hills, which are covered with chert.

In the southeast quarter of section 3, 200 yards west of the ravine just mentioned, the marble occurs at the base of the hill; while 100 yards further west the Calciferous rocks appear along the hillsides, underlying the marble.

At the head of Cold Water Creek, in the southwest quarter of section 3 (17 N., 16 W), and the southeast quarter of section 4, the marble outcrops over an area of six to ten acres on the divide between Rush Creek and Water Creek, and is exposed on the heads of both streams; this place is known locally as the Cedar Glade. The marble occurs on the weathered exposures in slabs from one to eight inches thick, and is chocolate colored, gray, and variegated, some of it being very crinoidal, and all fossiliferous.

Clabber Creek.—The Clabber Creek valley lies mainly in the Silurian rocks. There is no continuous marble outcrop on

either side of the creek, but on the highest points are several small isolated areas. One narrow strip of marble occurs on the southwest side of the creek, on the divide between Clabber Creek and Rush Creek, where the marble is 20 feet in thickness, and is overlain by 80 feet of chert; the highest point is 350 feet above Clabber Creek. On the east side of the creek are not less than three small marble areas on the high points.

On Mt. Ephraim, in 18 N., 15 W., section 29, the south part, on the dividing ridge between Clabber Creek and Blue John Creek, is a bed of the St. Joe marble 30 feet thick, extending over an area of about 40 acres; it has only a slight covering of chert and gray limestone in places. It occurs in layers from two to four feet thick, solid and firm in texture, having a dark chocolate color at the bottom, but growing lighter towards the top. It extends but 400 to 500 yards back from the south end of the ridge, where it is replaced by the underlying rocks; yet other areas probably occur on the ridge further north between Mt. Ephraim and Hall's Mountain.

A thin bed of chert and slight traces of the marble occur on the high ridge between Clabber Creek and the headwaters of Warner's Creek, in the eastern part of 18 N., 15 W.

CHAPTER XXII.

THE DISTRIBUTION OF THE ST. JOE MARBLE—*Continued.*

CROOKED CREEK VALLEY.

(The Harrison map sheet.)

General features of the marble, south side of Crooked Creek.—Only a narrow ridge separates the basin of Crooked Creek from that of Buffalo River, and it is in this very irregular, chert-covered ridge that the largest quantities of marble are exposed. While the hills bordering Crooked Creek are higher on the lower course than on the upper, there is less marble in them, as the general south and west dip of the strata causes a much larger exposure of the underlying formations. Thus on the lower course the marble occurs only on the high dividing ridge between the Crooked Creek and Buffalo River basins, while on the upper part of the stream it is on the hills bordering the creek, as well as on the tributaries as far west as Harrison, where it disappears beneath the overlying chert. All the marble in the Crooked Creek valley and north of it is the St. Joe marble of the Boone chert, no St. Clair marble occurring north of Buffalo River valley except the small disintegrated exposure in Pine Hollow, 17 N., 18 W., section 12.

Mill, Greasy, Hampton, Clear, and Huzza Creeks are the chief tributaries of Crooked Creek from the south; on the first two of these there is but little marble, while large exposures occur on the other three, the most promising being on the headwaters of Hampton and Clear Creeks.

Hall's Mountain.—The St. Joe marble occurs on Hall's Mountain, beginning in 18 N., 15 W., section 9, the southwest quarter, near the top of the hill, and west of the head of Blue John Creek. It lies so near the top of the mountain that in places it has been entirely removed by erosion, leaving isolated patches here and there; the first of these patches

ends in the south part of section 8, and north part of section 17, where the saccharoidal sandstone extends to near the top of the ridge. This condition is almost repeated about a quarter of a mile east on this island where all the overlying chert has disappeared, but the marble still continues to cap the ridge. To the west there is a larger island extending to the west part of section 7 (18 N., 15 W.). The ridge is narrow and the marble bed is correspondingly narrow; in one place about a quarter of a mile from the east end of the exposure it is not more than 200 yards wide and forms the cap rock of the ridge. An interval of a quarter of a mile occurs between this island and the next one, which is the largest and most irregular one and which lies mostly in 18 N., 16 W., covering nearly all of section 13, and parts of sections 11, 12, 14, and 24. The finest exposure is in the northeast quarter of section 11, at a cave in the side of the mountain, where the red marble 25 feet in thickness is overlain by 20 feet of a pinkish gray limestone. In most places where exposed along the hillside, the marble is much weathered, occurring in thin shaly slabs, but in this cave where it has probably not been exposed to the elements so long, it occurs in a solid mass. At the Lone Cedar and other places along the mountain, there are beautifully colored, finely crystalline, compact, but thin and irregular slabs of St. Joe marble. There is another small marble island on the peak called Bald Jesse in 18 N., 16 W., section 24, the southwest quarter, where the much weathered marble lies near the top of the mountain; at this point it is 600 feet above Yellville.

Mill Creek.—The marble on the west end of Hall's Mountain is the only outcrop of any prominence in the Mill Creek basin. A few weathered boulders occur in 18 N., 16 W., section 35, and closer examination might show some on the high ridge in sections 29, 30, and 32.

Greasy Creek.—At the extreme head of Greasy Creek in 17 N., 17 W., sections 1 and 12, weathered outcrops of the St. Joe marble occur. On the east side of Greasy Creek through 18 N., 17 W., and on the west side on the ridge between this

stream and Hampton Creek, traces of the marble occur in the chert debris.

Hampton Creek.—The next tributary of Crooked Creek west of Greasy Creek is Hampton Creek, which empties into Crooked Creek close to the mouth of Clear Creek in 18 N., 17 W., section 7. No marble occurs on the hills at the mouth of the creek, and there are no heavy outcrops below Bruno in 17 N., 17 W., section 3, but on the numerous ramifying tributaries above Bruno extensive areas are exposed.

Glenn Hollow, the long tributary east of Bruno, drains the northeastern part of 17 N., 17 W., and the northwest of 17 N., 16 W.; the St. Joe marble occurs in the hills on both sides of this hollow, but as in many other places, it shows in larger quantities on the hillsides facing south than on those facing north. In 17 N., 17 W., section 10, the northeast quarter, on the hill at the head of the ravine south of Mr. Angell's house, three acres of the St. Joe marble are uncovered and much more has but a slight covering of chert. Heavy ledges of the marble outcrop on the north side of the creek in section 12 and on both sides in section 7 (17 N., 16 W.).

The outcrop of marble is almost continuous around the heads of the numerous ravines south and southwest from Bruno, where in all the exposures it occurs in slabs from two to six inches thick, which in general are finely crystalline, quite firm and resonant. The varieties in color are plain dull red, mottled red and gray, and purplish and gray variegated. The gray limestone of the Boone chert outcrops in several places in sections 10 and 15 (17 N., 17 W.).

A spring at Bruno in section 3 (17 N., 17 W.), in rocks of Lower Silurian age, is said to be intermittent in dry seasons. It flows a strong stream for a few hours and suddenly stops for an interval. No regularity has been observed in the intervals of flow or quiescence.

Clear Creek.—Clear Creek, the largest affluent of Crooked Creek, was formerly called South Crooked Creek. It is almost as large as Crooked Creek and fully as crooked, winding through a comparatively wide and fertile valley. The greater

part of the valley is dotted with prosperous farms and good farm buildings. The marble is in most places some distance from the creek and near the top of the hill, yet owing to local dips of the rocks it is on the creek bank in places. But little marble of value occurs in the lower part of the valley, where the bed is thin, very shaly, and crumbling where exposed, while in some places it has entirely disappeared. A beautiful buff colored dolomite ("cotton rock"), which would make a valuable building stone, outcrops among the Silurian rocks on the lower course of Clear Creek.

White Oak Branch is the first tributary of any size on the west side; it joins the creek in 18 N., 18 W., section 15, the northeast quarter, and drains about three square miles underlain with marble. The finest exposure in this area is the one on the east branch southwest of John Milum's, from which Mr. Miller worked some good tombstones out of the gray and red variegated varieties. The gray marble seems to be of better quality than the underlying red.

In Sand Hollow, the tributary of Clear Creek next west of White Oak Branch, but little marble is exposed, being in most places concealed by the broken chert.

Some pretty variegated marble outcrops in the next ravine in the south part of section 16 (18 N., 18 W.). In sections 21, 28, and 27 the marble is near the base of the hill close to the stream; in section 27, the northwest quarter, it appears on the creek bank 40 feet above the water on the west side, but is not visible on the east side.

The marble appears in places through the chert debris on both sides of Meek's Creek for more than four miles from its mouth, the western limit being 18 N., 19 W., section 26, the northeast quarter, where it disappears beneath the chert. The finest surface marble on this stream is in section 25 (18 N., 19 W.), the northwest quarter, near Mr. Sherfey's blacksmith shop. But little marble of value occurs on Meek's Creek, however, for it is mostly in thin, irregularly bedded, crumbling slabs.

On the east side of Clear Creek in the southeast of township 18 N., 19 W., the marble is exposed in various places, but in

small quantities and of poor quality. It lies so near the surface, being covered with but a thin bed of chert in many places, that it has been leached away, but has aided in making the soil of the King's Prairie region very fertile.

The tributary on the east side of Clear Creek, known as Pine Hollow, contains large exposures of the St. Joe marble around the head, in 17 N., 18 W., sections 1, 2, 11, and 12. In the ravine known as Jones Hollow, in the southwest quarter of section 1, the marble outcrops in thin slabs and crumbling ledges, along the hillsides for half a mile and along the base of the hills for half a mile further. On the east side of Pine Hollow the finest exposure observed was at Mr. Williams' house in section 12, the northeast quarter, where from 10 to 30 feet show through the chert debris, mostly in thin slabs, some of which are variegated.

In Rock Hollow in the west part of section 12 (17 N., 18 W.), is one of the finest outcrops of marble in the Clear Creek valley; the bed is 60 feet thick and lies at or near the base of the sloping hillsides for nearly a mile along the ravine. It is underlain by the saccharoidal sandstone, and overlain by from 30 to 100 feet of chert, near the top of which occasional boulders of the gray limestone appear. The marble shows on the surface in strata from one inch to two feet in thickness, averaging three or four inches, and varies in color through different shades of light gray, and variegated red and gray; one especially fine layer, near the bottom, is of a light gray color with a slight tinge of pink, highly crystalline, non-fossiliferous and about three inches thick on the surface. This marble is easily accessible in all directions and has a local use for chimney building.

Above Rock Hollow in section 12, the northeast quarter, at the forks of Pine Hollow, the marble bed exposed is 45 feet thick; the bottom layers, which are almost entirely disintegrated on the surface, closely resemble the St. Clair marble in appearance; near the top of the bed the layers, which are from one to eighteen inches thick, become firm and solid, of a light red color, finely crystalline, and slightly crinoidal.

The next tributary of Clear Creek above Pine Hollow is Hog

Creek, the longest one of the many tributaries. The hills at its junction with Clear Creek are composed of the Silurian rocks, traces of the marble first appearing on the tops of the hills a mile or more from the mouth. In 17 N., 18 W., section 6, in the north part of the section, along the small tributary flowing east from Rally Hill, the marble, which is exposed in layers from one to three inches thick, is of a light red and gray color, and contains intercalary chert. Apparently the St. Joe marble occurs here in a very thin bed and is not distinctly separated from the gray limestone. In 17 N., 19 W., section 12, at the old Vance place, some fine variegated slabs of red marble occur intermingled with much that is worthless. The large chimney in the Vance house, built of this marble many years ago, was apparently in as good condition in 1890 as when first built. Through sections 1 and 2 (17 N., 19 W.), the marble extends along the creek bed and base of the hills, but no outcrop of commercial importance was observed. A local anticline in sections 3 and 10 (17 N., 19 W.) causes the Calciferous sandstone to reappear; it occurs along the base of the low hills for about one mile, the overlying marble outcropping in some places, but in many places being covered with the chert debris. On the north side of the creek in section 3, the southeast quarter, east of the Valley Springs-Western Grove road, the marble outcrop is about 20 feet thick; some of the layers are light gray, faintly tinged with red and highly crystalline, while others are of a dark red color with greenish stripes and spots. An analysis of the two colors separately for manganese and iron showed no manganese in either, and 2.12 per cent. of ferric oxide in the red color and 1.19 per cent. in the green.*

Large quantities of gray limestone containing intercalary and nodular chert are exposed at Rally Hill and east of Valley Springs. It is crystalline and fossiliferous, and if it could be obtained free from the chert would make good building stone.

*While the iron was estimated as ferric oxide it was not proven to be such; it is probable that the iron in the red variety is in the ferric state and that of the green in the ferrous.

Good building stone could be obtained from sandstone of Silurian age on the north side of Hog Creek southeast of Rally Hill.

The next tributary of Clear Creek, south of Hog Creek, is known as Marshall Prairie Creek; it is on the same side of the creek and somewhat similar to Hog Creek in its geological formations, but the quality of the surface marble is superior. Near the mouth the marble is on the top of the hills, but is mostly concealed by chert debris. In section 8 (17 N., 18 W.), the southwest quarter, on the west side of the creek, is an outcrop of red marble 40 feet thick on top of the high sandstone ledge; it appears at the surface in slabs from two to three inches thick, and is red, gray, and variegated in color. In section 18 (17 N., 18 W.), the outcrop is 45 feet thick on each side of the creek; the layers are from two to ten inches thick, and the marble is colored like that in section 8. Two varieties occur at this place which were not found elsewhere, one being mottled light red and gray, coarsely crystalline, very solid and firm, and highly fossiliferous; the fossil fragments being small can scarcely be distinguished on a fresh surface. A partial analysis shows it to contain a faint trace of manganese and 0.44 per cent. of ferric oxide. The other variety referred to is coarsely crystalline, variegated, purple and yellowish gray in color, with many crinoid fragments; it contains a faint trace of manganese and 1.26 per cent. of ferric oxide. A slab of marble 8 feet by 2½ feet by 4 inches, one side of which was ground, was taken out here many years ago, and was mentioned by Dr. Owen in his report of 1858*. It was used as a currier's table at the tan-yard at Yardell, Newton county, and although it has now been exposed more than thirty-five years, it shows no signs of decay.

In the Knob Cemetery, a mile and a half northeast of Western Grove, are a dozen or more tombstones of this native marble, and a number are also in the cemetery half a mile north of Western Grove, all of which are comparatively new, and some of them very handsome stones.

*First report of a Geological Reconnoissance of Arkansas, 1858, p. 87.

In township 17 N., 18 W., around the headwaters of Clear Creek, the red marble outcrops abundantly and is very much like that on the headwaters of Tomahawk and Mill Creeks, the bed being a little thinner, and the topography differing in having lower hills, with the streams flowing through broad shallow basins in place of the deep, precipitous gulches of Tomahawk and Mill Creeks. From Glenco down-stream the high and steep hills are composed of the Calciferous rocks, and only the higher ones are capped with marble and chert.

There are numerous exposures east and southeast of Glenco, the largest and finest of which is at Mr. Keith's in the west part of section 23 (17 N., 18 W.), in the vicinity of the big spring.

On the east side of the creek in the small ravine southeast of Glenco, in section 27, is an extensive exposure of both the St. Joe marble and the gray limestone, the upper layers of the limestone being not completely crystallized.

On the tributary to Clear Creek, flowing north through the southwest part of township 17 N., 18 W., sections 20, 29, 30, and 32, the marble is exposed in thin much weathered slabs.

On the hill west of Clear Creek, in the southwest quarter of section 28 (17 N., 18 W.), and the northwest quarter of section 33, is a large outcrop of red marble thirty feet thick and continuous for one mile. Near the upper part of this bed is a solid ledge ten feet thick, both above and below which it is in thin weathered slabs. None of the gray limestone is exposed, and the broken white chert overlying it is very fossiliferous.

Going north and west from St. Joe on the old Carrollton road, the first place in which the red marble is visible on the Clear Creek side is on the low hillside at Mr. Wright's in 17 N., 18 W., section 34; the outcrop is five feet thick and the rock is crumbling and shaly and of a deep red color. It appears at intervals from this point to Mr. Tyler's in section 34, the southwest quarter, whence the outcrop is almost continuous to Clear Creek. The bed is about 20 feet thick and the layers which are four inches thick, are generally much weathered, lumpy and

crumbling. Fine ledges of marble are visible on both sides of Clear Creek in 16 N., 18 W., section 4, up-stream to a short distance south of Mr. Kilburn's house in the south part of the section where the marble disappears beneath the overlying chert in the creek bed; but it extends up a branch ravine from the southwest a quarter of a mile further into section 9, the northwest quarter. On the hill on the west side of the stream in section 4 (16 N., 18 W.), between Mr. Trammel's and Mr. Kilburn's, four or five acres of the marble are uncovered, appearing on the surface in loose slabs from one to three inches thick.

Crooked Creek between Clear Creek and Pedlo.—On the south side of Crooked Creek, west of Clear Creek, the marble outcrops mostly in thin strata from one to eight inches thick. West of Powell in 18 N., 18 W., section 2, and in 19 N., 18 W., sections 35 and 36, eight to ten acres of pretty, variegated, and finely crystalline marble are exposed on the top of a hill, a sample of which shows a specific gravity of 2.716. Some of this marble has been used for building chimneys in the neighborhood.

In section 4, the southeast quarter, and section 9 (18 N., 18 W.), the north part, large quantities of the marble are exposed on top of the hill near Crooked Creek.

Pedlo Creek.—Near the top of the hill half a mile east of the mouth of Pedlo Creek is a fine exposure of the St. Joe marble, one ledge of red marble being three feet thick, with layers from two to four inches thick of variegated marble both above and below it. A few weathered exposures appear in the ravines at the head of this creek, but in most places the outcrop is concealed beneath the chert debris, while the Calciferous rocks form the hillsides.

Huzza Creek.—The finest marble outcrop on Huzza Creek is in 18 N., 19 W., sections 4, 5, and 9, west of the creek, on the hill between Huzza Creek and Crooked Creek, where it outcrops on the sides and on the top of the hill east of the Bellefonte-Lead Hill road. Among the varieties in color are red, gray, variegated, and rose colored; the latter, which is compact, fine-grained, and highly crystalline, is the most abundant

and it has weathered into thin slabs from two to five inches thick. On account of the ease with which this marble can be obtained, it has had a local use for tombstones and chimney building.

Up Crooked Creek from the mouth of Huzza Creek, the marble outcrops at intervals to within one mile of Harrison, where it disappears beneath the chert. In 18 N., 20 W., section 11, Mr. Wilson has built a house of light gray and pink colored marble which presents a very pleasing appearance. The stone has also been quarried in section 10, the northwest quarter; it is crystalline, pink and gray in color, occurs in slabs two to four inches thick, and contains intercalary chert.

There is one small outcrop of the St. Joe marble above Harrison, but it is of no economic importance. The valley of Crooked Creek, above Harrison, which is wider and shallower than that below Harrison, is mostly in the Boone chert, and contains one of the most prosperous farming communities of the state. Four miles south of Harrison the creek divides, one branch heading in Sulphur Mountain and Boat Mountain, and the other from the southwest in Gaither Mountain.

(The Lead Hill map sheet.)

The north side of the Crooked Creek valley resembles in its general features the south side, but as it is narrower than the south side, it has fewer large tributaries.

In 18 N., 20 W., section 2, the southwest quarter, and section 3, the southeast quarter, on the north bank of the creek, is a bluff 50 feet high which contains a prominent exposure of red marble. A section at the lower end of this bluff shows 12 feet of Calciferous sandstone, and 60 feet of red and gray marble covered with chert. At the lime-kiln on the upper end of the bluff, where some lime has been burnt, the red rose colored, and red and gray variegated varieties, with intercalary chert, occur in solid, firm layers, one to six inches thick, but with very uneven surface, so that a layer six inches thick in one place may be only two or three inches thick a few feet away.

White Oak Creek.—The Calciferous sandstone, overlain by the

St. Joe marble, extends up White Oak Creek nearly two miles into the northern part of section 28 (19 N., 19 W.), while the marble extends nearly a mile further into the southwest quarter of section 22, where it outcrops in large bluffs about Judge Robert's spring. It is mostly of loose texture on the weathered surface and contains some intercalary chert. Sand Lick, the tributary of White Oak from the northwest, which joins it near its junction with Crooked Creek, was explored by Mr. G. H. Ashley of the Survey, who visited the head of this tributary in the spring of 1892. He reports an interesting area of disturbance in the strata, in which occur large quantities of chert breccia with small quantities of quartzite, sphalerite ("jack"), and disintegrated limestone, which from the description resembles the St. Clair marble.

Above the mouth of White Oak a local fold in the rocks brings the marble higher on the hills and further from Crooked Creek. It outcrops around the head of Silver Valley, and thence along the hill to Short Creek, in 19 N., 20 W., section 35, where it is again lower on the hill, being but 70 feet above Crooked Creek. On the hill east of Short Creek, in the east part of section 35, it is highly crystalline, compact, light red and gray in color, contains some intercalary chert, and has a total thickness of 60 feet exposed.

Big Sugar Orchard.—The marble occurs on the long narrow ridge between Big Sugar Orchard and Crooked Creek, but is so much decayed that no heavy body of it could be found. It outcrops on both sides of Big Sugar Orchard through the southern and western part of township 19 N., 18 W., and the northeast part of township 19 N., 19 W. The finest outcrops are about the head of Mill Hollow, in 19 N., 18 W., sections 4 and 9, in the extreme head of which, in section 5, the marble appears more or less crumbling on the exposed surface, but below in section 4, about Mr. Rhodes' mill, it appears much firmer in texture. Several varieties occur near the mill, one of which is quite picturesque and variegated, being of red, yellow, greenish gray, white, and dark colors, irregularly ringed and striped, and presenting quite a fancy appearance on a polished

face, but on all the weathered surfaces it is crumbling and shelly, the lines of beauty proving often lines of weakness; as an ornamental stone, where strength is not a requisite, it would be highly prized. There is also a crinoidal variety of great beauty, resembling that described at St. Joe and Wells Creek.* A fine, close-grained, compact, red and gray mottled variety takes a beautiful and lasting polish, as may be seen in the jambs and arch rock of Mr. Rhodes' chimney, which has been standing for several years; its fine-grained, homogeneous texture, combined with its pleasing colors, makes it a desirable ornamental stone. A chemical analysis of the last variety is given below.

Analysis of St. Joe marble from Rhodes' mill, Boone county.

Constituents.	Per cent.
Residue insoluble in hydrochloric acid	0.835
Titanic oxide (TiO_2)	trace?
Phosphoric acid (P_2O_5)	0.009
Alumina (Al_2O_3)	0.024
Ferric oxide (Fe_2O_3)	0.058
Manganic oxide (MnO_2)	0.071
Zinc oxide present, not determined	
Potash and soda (K_2O, Na_2O)	0.005
Magnesia (MgO)	0.160
Lime (CaO)	55.340
Loss on ignition (CO_2)	43.630
Total	100.177
Carbonate of lime ($CaCO_3$)	98.720

It will thus be seen that it is a comparatively pure limestone, with no elements of weakness in its composition. It is one of the heaviest of Arkansas marbles, having a specific gravity of 2.7191, weighing 169.94 lbs. per cubic foot.

Mr. Rhodes sent some polished samples of this marble to the North, Central, and South American Exposition at New Orleans, where they received considerable admiration, and were awarded a diploma.†

On Big Sugar Orchard Creek, above Mill Hollow, the marble outcrops at intervals along both hillsides, overlying the

*See pp. 282 and 291.

†See Chapter XIX. for other tests on the marble from this locality.

white sandstone up to 19 N., 19 W., section 11, the southwest quarter, near Mr. Keener's, where the sandstone disappears; while the marble continues along the valley and base of the hills to the middle of section 10, and disappears beneath the chert. In the southwest quarter of section 11, in front of Mr. Keener's house, are some fine solid ledges of a light gray colored marble, which appear very firm and solid, and well suited for building stone. A ledge six to ten feet thick of the red marble occurs at the big spring in section 10.

Tar Kiln Creek.—The marble is exposed in thin and heavy strata two inches to three feet thick with a total thickness of 50 to 60 feet, on the point of the ridge between Tar Kiln and Big Sugar Orchard Creeks and along the west side of Tar Kiln in many places to near the head of the creek in 19 N., 18 W., section 3. The most promising outcrop is on Coker Branch, sections 15, 16, and 22 (19 N., 18 W.). A section on the hill on the north side of the ravine in section 15, the southwest quarter, shows 80 feet of Silurian rocks overlain by 60 feet of marble capped with a heavy bed of chert. The heaviest stratum of the red marble exposed at this point is five to six feet thick and occurs near the bottom of the bed, with firm solid layers of the red and mottled, two to ten inches thick, both above and below the heavy ledge, making the total thickness 60 feet.

Little Sugar Orchard Creek.—Sugar Orchard Creek consists of three streams known as Little Sugar Orchard, Tar Kiln, and Big Sugar Orchard. On Little Sugar Orchard the marble is exposed near the mouth of the creek in 19 N., 18 W., section 36, and in 19 N., 17 W., section 31; also at the head of the creek in 19 N., 17 W., sections 5 and 8, the outcrop between these points being marked from the topography.

Harris' Creek.—The road from George's Creek post-office to Dodd City crosses the marble escarpment in 19 N., 17 W., section 15, the southeast corner, from which place the marble outcrops at intervals on top of the big sandstone ledge around the head of Harris' Creek and west to the mouth of Sugar Orchard Creek.

George's Creek.—In ascending Crooked Creek, the first marble on the north side of the valley is at the head of George's Creek, where it forms an escarpment close to the top of the hill around the numerous small ramifying tributaries, and is concealed in places by the chert debris. The maximum thickness found was 40 feet; it occurs in slabs two to ten inches in thickness, and is red and variegated in color.

CHAPTER XXIII.

The Distribution of the St. Joe Marble—*Continued.*

BETWEEN CROOKED CREEK AND KING'S RIVER.

(Lead Hill map sheet.)

Between Crooked Creek and King's River the principal tributaries of White River on the south side are Falling Ash, Jimmy's, Sister, Music, Coon, Lower and Upper Sugar Loaf, Bear, Long, and Indian Creeks; all of which, except the last two, head in the long, narrow, very irregular dividing ridge between Crooked Creek and White River. The marble lies near the top of this ridge, forming an irregular rugged escarpment around the head waters of each of these creeks and extending down the streams a variable distance depending on the local dip in the rocks and the height of the hills. On the lower part of each of these watercourses and on the hills along the river, the Silurian rocks, consisting of sandstones, limestones, and chert, are exposed through a thickness of several hundred feet.

Lee's Mountain.—Lee's Mountain is the name given to the high dividing ridge between Jimmy's Creek on the west and Falling Ash Creek, Jenkins Creek, and White River on the east. It is mostly composed of siliceous rocks of Silurian age, but in 19 N., 16 W., there are four small islands of Carboniferous rocks consisting of St. Joe marble capped with Boone chert.

The entire thickness of the marble is not exposed, being partly concealed by the chert fragments. In 19 N., 16 W., section 23, the northeast quarter, the St. Joe marble has been quarried to a limited extent for local use. It is chocolate colored, encrinital, solid, homogeneous, and occurs in irregularly bedded layers two to four inches thick, the total thickness of the outcrop being about five feet.

A section of the different strata on the mountain west of Flippin is shown below.

Section of Lee's Mountain west of Flippin.

	Feet.
Boone chert	20
St. Joe marble	20
Sandstone (Silurian)	30
Siliceous limestone	50
Sandstone	50
Intercalary sandstone and limestone	40
Chert and siliceous limestone	130
Magnesian siliceous limestone	80
Total	420

The area between Lee's Mountain and White River is covered with sandstones, cherts, and siliceous limestones of Silurian age.

Jimmy's Creek.—On the south side of Jimmy's Creek marble outcrops from the head of Moccasin Fork, in 19 N., 16 W., section 16, to and around the head of the creek, in 19 N., 17 W., sections 1, 2, and 3; while on the north side it occurs in somewhat extensive ledges in the northwest part of 19 N., 16 W., and the southwest part of 20 N., 16 W. Traces of the marble occur as far east as 20 N., 16 W., section 23; but little, however, is exposed, the bed being concealed in most places by chert fragments.

Sister Creek.—No marble was observed on Sister Creek, but the overlying chert extends along the hillsides around the head of South Sister Creek, and it is probable that a more extended search would have shown some outcroppings of marble, although the greater part of the bed has decayed.

Music Creek.—Music Creek is the next tributary above Sister Creek. In 20 N., 16 W., section 19, is a bold exposure of the red marble, which is much weathered and somewhat crumbling on the exposed surfaces. It continues along the hillsides through the greater part of township 20 N., 17 W., the outcrop being especially prominent at the two springs which form the headwaters of West Music. In 20 N., 17 W., section 35, the northwest quarter, at the Greaver Spring, the marble measures

50 feet in thickness, is red and variegated in color and crinoidal in places. The overlying chert contains some intercalary gray limestone. At the Marble Falls spring, on A. L. Dirst's place, in the middle of section 27, same township, at the head of another tributary of West Music Creek, the marble is well exposed in a bed 50 feet thick, the top of which is 190 feet below Mr. Dirst's house, a mile from the spring. The marble outcrops in a bold bluff, from beneath which the spring issues; in this bluff are several varieties of marble, the most characteristic ones being red, pink, and pink and light gray mottled. The last mentioned has the finest texture, being finely but completely crystalline, susceptible of a beautiful polish and very durable as a building or ornamental stone. It appears on the weathered surface in layers from two to eight inches thick, but some or all of these stratification planes possibly disappear in the body of the marble. The exact contact of the marble with the underlying rocks could not be seen at the spring, but the interval beween the St. Joe bed and the underlying gray limestone is only four inches; the limestone is ten feet thick and is underlain by white sandstone and blue limestone.

The marble outcrops at intervals west and north of Marble Falls spring, on the other branches of Music Creek, in sections 27, 22, and 15 (20 N., 17 W.), yet in many places it is so much decayed as to be concealed beneath the broken chert. A white stalagmitic "onyx" marble occurs in section 14 of this township, and is being quarried to some extent by Mr. A. L. Dirst, the owner of the property (see Chapter XXVI.)

Coon Creek.—There is a small exposure of red and purplish red marble at the tops of the hills around the head of Coon Creek in 20 N., 17 W., sections 9 and 5.

Lower Sugar Loaf Creek.—The numerous small tributaries of White River for many miles above Coon Creek flow over the Calciferous rocks, no part of their course being in the marble. Lower Sugar Loaf Creek heads in the marble-capped hills south of Lead Hill, and about its headwaters there are large quantities of marble. The outcrop may be traced around the north face and near the top of the hill from the head of

Coon Creek to the head of Locust Branch and thence along the hillsides south of this branch through 20 N., 17 W., section 6, and in 20 N., 18 W., sections 12 and 13; on the south side of the hill north of Monarch post-office; on the hills on both sides of Lead Mine Hollow in the west part of 20 N., 17 W., where large quantities of magnesian limestone are exposed underneath the marble. In Flat Hollow, the next ravine southeast of Lead Mine Hollow, the marble is exposed in 20 N., 17 W., section 21, about two miles from the mouth of the stream, with slight traces on the higher hills towards its mouth. In Chapman Hollow, the next one to the south that joins the main creek at Mr. Jenkins', there are large outcrops of marble near the middle of section 29 (20 N., 17 W.). At Chapman spring in the western half of section 28 is a marble bluff very similar to those mentioned on Music Creek, but the rock is a little more crumbling and fissile on the weathered surface. In Pigeon Roost Hollow, the next affluent of Lower Sugar Loaf Creek, south of Chapman Branch, more and finer marble is exposed than in any of the others named along Sugar Loaf. The marble is exposed in places above (southeast of) this affluent to the head of the creek at Dodd City in 19 N., 17 W., section 4. Some years ago Mr. Dodd quarried some of the red marble and sawed it at his sawmill in Dodd City, but it had only a limited local use and none has been sawed for several years. On another small tributary of Lower Sugar Loaf from Markle's mill in 20 N., 17 W., section 31, the red marble is exposed. It outcrops at intervals around the heads of the numerous tributaries west of this point, to the head of Upper Sugar Loaf in the southwest part of 20 N., 18 W., the outcrop being for the most part in the southern tier of sections of township 20 N.

Upper Sugar Loaf.—Much marble is exposed in 20 N., 18 W., sections 31 and 32, and in 20 N., 19 W., section 36, but for the most part it is crumbling and shelly. The finest exposure is in 20 N., 19 W., section 25, on the hill south of Col. Philip Moore's house, at which place a section shows 240 feet of Calciferous rocks overlain by 40 feet of red marble, which in

some places is capped with chert; but in other places the marble itself caps the narrow ridge, where it may be seen in great slabs from 40 to 100 feet across, forming an irregular bluff on each side of the hill. Part of it is in thin shaly slabs, part in ledges eight to ten inches thick, while near the bottom of the bed are two to three inches of intercalary chert. From this exposure the outcrop is almost continuous westward around the heads of the other tributaries of Upper Sugar Loaf, but it generally presents a crumbling shaly surface. Some fine solid ledges occur, however, in 20 N., 19 W., the southeast quarter of section 22 and the northeast quarter of section 27. Some nicely colored slabs, but no heavy ledges, occur on the peak west of Belden Spring in the north part of section 22. In the east part of section 29 (20 N., 19 W.), it has a loose and crumbling texture. On the hill in the southwest part of section 16 some beautiful purplish red colored boulders show through the broken chert.

Between the high chert-covered ridge and White River is an elevated, scantily timbered region covered with chert and magnesian limestones of Silurian age.

Bear Creek.—Bear Creek drains more of the chert area than do the creeks further east, and has a greater length of the marble outcrop within its hydrographic basin, but the marble exposed both in quality and quantity is inferior to that on the Sugar Loaf Creeks. It is exposed on both sides of Malden Creek, in 20 N., 19 W., sections 5, 6, 7, 8, and 18, and in 20 N., 20 W., section 1; on Cheatham and Marble Creeks in 19 and 20 N., 20 W., and at Bear Creek Springs (Francis post-office), in 19 N., 21 W. It is doubtful, however, if any of these exposures will be found to contain marble of any value; it may be used for lime or building foundations or chimneys.

Bear Creek empties into White River close to the state line, above which the river makes a long bend northward into the State of Missouri, from range 26, north of Eureka Springs, where it first leaves the state, to range 19, near the mouth of Bear Creek, where it re-enters it. Its tributaries from Arkan-

sas in that interval are Bee Creek, Long Creek, Indian Creek, and King's River.

(Carrollton map sheet.)

Bee Creek.—Bee Creek drains the northeast part of township 21 N., 21 W. It heads in numerous ravines at Omaha church and post-office in the Boone chert, through which the streams have cut their way into the marble and underlying Silurian rocks. Large quantities of marble are exposed in sections 14 and 23 (21 N., 21 W.), about the junction of numerous ravines.

Long Creek.—Long Creek drains most of the area between Gaither Mountain and the Missouri state line, comprising the north and north central part of the Carrollton map sheet. It heads in the Millstone grit and underlying sandstone and shales south, southeast, and southwest of Carrollton, but the greater part of its course is through the Boone chert. There are three separate marble areas in the valley of Long Creek: one in 19 N., 22 W., section 2; one on Yocum Creek in 20 N., 23 W., sections 19, 30, and 31; and a large and more extended area near where the creek leaves the state of Arkansas, on Cricket Creek, and around the junction of Long and Yocum Creeks.

The marble is exposed on the south side of Blair Branch, in 21 N., 22 W., section 11, and on the hill east of Long Creek in the southwest quarter of the same section.

The marble outcrops on both sides of Cricket Creek nearly to the head of the stream, a quarter of a mile above Mr. Patrick's steam sawmill in 21 N., 21 W., section 27, the northwest quarter.

South of Cricket Creek the finest exposure is on the west side of Long Creek at Raven Bluff, section 26 (21 N., 22 W.). The marble at the north end of the exposure on the bluff is 200 feet above the creek; 300 yards further southwest it is overlain by 100 feet of chert. Immediately south of the bluff the marble is at a much lower level; in the middle of section 35, less than a mile up-stream, it is not more than 30 feet above the stream; and in the south part of section 35 it disappears be-

neath the chert. A more detailed examination may show the presence of a fault in the strata near the south end of the bluff; such a fault is suggested by the sudden change in level made by the outcrops.

The marble outcrops on the bluff on the south side of the creek in section 22 (21 N., 22 W.), the southeast quarter; in the ravine south of William Davis' house in the south part of 22; and on the south side of Yocum Creek in section 27, the northwest quarter. Local folds cause the marble to outcrop at different elevations above the water along Yocum Creek in sections 20 and 21; the upper limit on this part of the creek is in section 20, the southwest quarter, more than a quarter of a mile below Winkle's mill. Above Winkle's mill in sections 19 and 30 are several prominent chert bluffs, one of the highest of which is in the northeast quarter of section 30 on the south side of the creek.

The only other outcrop of marble on Yocum Creek is on the monoclinal fault in 20 N., 23 W., sections 19, 30, and 31, and in 20 N., 24 W., section 24. It is exposed on the hills north of Brazael school-house in crumbling ledges which dip to the east, outcropping along the north side of the wagon road east of the school-house, as far as the ravine from the north in section 19 (20 N., 23 W.). At the mouth of the small ravine from the south in section 30 (20 N., 23 W.), it is exposed in broad sheets in the bottom of the hollow, with a dip to the east of 5° to 10°. Farther up the ravine the marble outcrops along the east side, and the underlying Silurian rocks on the west side for half a mile from the mouth, above which the Silurian rocks cover the whole area, the marble outcropping again with a dip of 12° to 15° east in another small ravine farther south, in section 31 (20 N., 23 W.).

On Long Creek above Raven Bluff there is a small exposure of much weathered marble on the creek bank 100 yards or more south of Shaver post-office, and a larger exposure of finer quality south and west of Dr. Sims' house in 19 N., 22 W., section 2, which continues as far south as Zeigler's mill in the southwest quarter of the section.

The rocks are more or less folded in different parts of the Long Creek valley, especially so in 21 N., 22 W.; 20 N., 23 W.; 19 N., 22 W.; and 18 N., 22 and 23 W. The only faults observed are, the one at the head of Yocum Creek and the one observed by Mr. Ashley in 20 N., 21 W., section 18, at the parting of the chert and Batesville sandstone. Yet as before suggested a fault may occur near the south end of Raven Bluff in 21 N., 22 W., section 26, and a more detailed examination might show displacement in the strata in 18 N., 22 W., sections 5 and 6, and 18 N., 23 W., sections 11 and 12, where the strata are considerably disturbed.

A marked topographic feature of the valley is the prominent ledge of Millstone grit capping the mountains south of Carrollton and the isolated areas southwest and northwest of Carrollton, forming conspicuous features of the landscape along any of the roads from Carrollton to Osage Creek, and also from Carrollton to Green Forest. The more southern route between Carrollton and Green Forest, the road running west from the forks three quarters of a mile south of Hottentot post-office, passes over large areal exposures of Marshall shale* in 19 N., 22 W., section 19, and 19 N., 23 W., section 24, which is also exposed in other places along the road.

Indian Creek.†—Indian Creek rises in the hills northeast of Berryville and drains an area of silico-magnesian rocks and chert of Silurian age; the valley is bounded on the east by an escarpment of St. Joe Marble overlain by Boone chert, with several marble and chert islands at the headwaters and along the east side of the creek. The outcrop of marble along the east side of the valley is winding and very irregular, but marks in its general course the monoclinal fault that passes west of

*In several places this shale has been prospected for coal, but of course without success. The most striking feature of the landscape by the more northern road between the two villages named, which is the one commonly traveled, is a magnificent elm tree in 19 N., 23 W., section 12, which possibly stands without a peer in the state.

†There is another Indian Creek west of White River described in the following chapter.

Green Forest and occurs on Osage Creek and the tributary of Yocum near Brazael school-house. The outcrop is most prominent in 20 N., 24 W., sections 11 and 12; in 21 N., 24 W., section 35, on the north side of the Berryville-Springfield road in the ravine east of Indian Creek; and sections 23 and 26 in the ravine east of the big spring, and on the hill north of the spring; in all these exposures the strata dip east. On Brushy Mountain, situated on the section line between sections 15 and 16 (21 N., 24 W.), the marble forms an escarpment around the mountain, 350 feet above Indian Creek.

On Pilot Mountain, 20 N., 24 W., section 24, the northwest corner, the marble forms a conspicuous ledge visible several miles distant. The marble is 35 feet thick, overlain by 50 to 75 feet of Boone chert and underlain by magnesian and siliceous limestone and chert of Silurian age. The bottom of the marble at the east end of the mountain is 270 feet above Brazael school-house, and dips toward the east. In section 23 (20 N., 24 W.), the southwest quarter, the Berryville-Yocum road crosses a low gap in the hill on the magnesian limestones of Lower Silurian age, but the St. Joe marble outcrops in sight of the road on either side; on the north side it is underlain by the black Eureka shale. It outcrops in a continuous ledge, 10 to 20 feet thick, around the east and north side of the ridge in sections 23 and 22 (20 N., 24 W.).

CHAPTER XXIV.

THE DISTRIBUTION OF THE ST. JOE MARBLE—*Continued.*

KING'S RIVER VALLEY.

(Carrollton and Eureka Springs sheets).

General features of King's River Valley.—King's River rises in the Boston Mountains close to the heads of White River, War Eagle Creek, and Buffalo River, from which point it flows in a very winding but general north direction, emptying into White River in the state of Missouri. The head ravines are in the Barren Coal measures, but all that part shown on the accompanying map lies in the Boone chert and underlying Silurian rocks. On the lower part of its course, in townships 20 and 21 N., 25 W., the erosion has been extensive and the Silurian area exposed is larger than that along any of the larger tributaries on the south side of White River, or on White River itself west of King's River. The amount of erosion is manifest to one standing on top of the marble escarpment or the chert covered hills and looking across the valley, ten to twelve miles in width to the outcrop of the same stratum on the opposite side. It is much more striking in comparison with the narrow valleys along White River and the deep narrow gorges along Buffalo River. The outlook across the valley from Grand View in 20 N., 26 W., section 13, is one of beauty; a large part of the valley is in cultivation, the town of Berryville can be seen eight miles away, as well as the rounded peaks and broken ridge east and northeast of that town. The scene from any of the high points on the east side of the valley is no less striking. In 18 and 19 N. the valley is much narrower, the marble outcropping nearer the river as one goes south, and finally dipping beneath the water-level in the south part of 18 N., 25 W., south of which the chert is the lowest formation exposed.

The strata are gently folded along the main stream in 18 N., 25 W., with a sharper dip in the south part of the township at the southern limit of the marble where possibly local faults occur. There is a small fault near the Lake in 17 N., 26 W., section 1, and a larger and more extensive one with a north-south direction in the Osage Creek valley.

The principal tributaries of King's River are Osage Creek, Piney Creek, Dry Fork, Rock House Creek, and Keel's Creek on all of which the marble is exposed.

Osage Creek.—Osage Creek is the largest tributary of King's River, being almost as large as the main river. There has been extensive erosion in the valley which is wider than that along most of the creeks of North Arkansas.

The Silurian rocks are exposed along the lower part of the creek, while the marble outcrops on either side of the valley; on the upper part of the creek, above 18 N., 23 W., section 9, the Boone chert is the surface rock to a few miles above Osage post-office, above which shales and sandstones are exposed. The prominent perpendicular ledge of rocks near the tops of the hills on the lower course of the creek is the St. Joe marble and that on the upper part is Millstone grit.

There can be no large tributaries, as the creek drains but a narrow strip between Piney Creek on the southwest and Long Creek and Yocum Creek on the northeast. Above Osage post-office the creek is in two parts, known as the East and West prongs of Osage Creek, each of which has many tributaries. On the south side of the creek, in the west part of 19 N., 24 W., and the east part of 19 N., 25 W., are several small tributaries, whose valleys are known as coves, such as Lundy's, Farmer's, and Lazy Coves, all of which contain nice farms.

The marble occurs only on the highest hills on the lower part of the creek, and there is none within several miles of the mouth of the creek, the nearest being on Round Mountain in 20 N., 25 W., section 33. The occurrence of numerous isolated peaks on which the marble is exposed, in 19 and 20 N., 24 W.,

gives the marble outcrop a spotted appearance. The peaks are most numerous east and northeast of Berryville. Three of the more prominent ones, which resemble each other in appearance at a distance, are known locally as the Three Sisters. There is a small rounded peak, on whose summit is the southeast corner of section 20 (20 N., 24 W.), which is capped with a thin bed of marble that is almost wholly disintegrated, leaving a loose, shelly, crumbling mass. On Bean Mountain, in section 33 (20 N., 24 W.), the northeast quarter, the marble forms an inconspicuous ledge underneath the chert cap. There are two other marble islands in 19 N., 24 W., sections 2 and 3, one of which extends into section 35 (20 N., 24 W.), near Mr. Z. Price's house, and another one in sections 11 and 12. There are many rounded points projecting between the numerous ravines from the dividing ridge, separating Osage and Yocum Creeks, which, from the west, look like isolated peaks. However, where it is not concealed by the chert debris, the marble forms a continuous outcrop along the east side of the creek from the south side of the Berryville-Yocum road, in 20 N., 24 W., section 22, to 18 N., 23 W., section 15, except a break in 19 N., 23 W., section 6, on the Berryville-Green Forest road, which passes through a low gap in the ridge. The marble outcrops on the west side of this ridge, on each side of the road, in section 1 (19 N., 24 W.), while on the west side of section 6 (19 N., 23 W.), as it approaches the fault line, it is concealed in the chert debris; and on the east side of the ridge, in the east side of section 6, the marble horizon is 200 to 300 feet below the surface.

In section 1 (19 N., 24 W.), about half a mile south of the wagon road, and in sight of the road when the leaves are off the trees, is a huge sandstone prominence, 50 feet high and 75 to 100 feet across, which apparently denotes deposition after erosion, as the magnesian limestones and Silurian chert occur in situ on either side of the sandstone. Along the slope southeast of the sandstone, siliceous and magnesian limestones, saccharoidal sandstone and siliceous, magnesian limestone breccia outcrop.

On the bluff northeast of the Bunch water-mill, in 19 N., 24 W., section 24, the marble is within a quarter of a mile of the creek, from which the outcrop extends around the heads of the numerous ravines of White Oak Hollow, in sections 18 and 19 (19 N., 23 W.), again outcropping close to the creek in the north part of section 30 (19 N., 23 W.). The road from Rule to Green Forest crosses the marble horizon in section 20 (19 N., 23 W.), the southwest quarter. The marble is not exposed in the road, but shows in a heavy ledge on the hill west of the road, near the southwest corner of the section, and in the ravine east of the road to near the middle of the section. The fault line mentioned as occurring in section 6 (19 N., 23 W.), crosses the ridge in the north part of section 20, where its presence is shown by the Boone chert on the west side, and the Batesville sandstone and Millstone grit on the east side. The fault continues in a direction a little east of south, showing plainly in section 33 (19 N., 23 W.), the west part, where it more strongly resembles a monocline than a fault, the strata in places dipping 15° to 20°, with a few small displacements; no displacement more than twenty feet in extent was observed, yet in the fragmental condition of the rocks larger faults might easily be concealed. Where the marble outcrops in the bottom of the ravine, west of the middle of section 33, it dips nearly east 15° to 20°, and is underlain by a bed of white sandstone 15 to 25 feet thick. For more than a quarter of a mile below (southwest of) the marble, the strata are more or less disturbed.

In 18 N., 23 W., on the section line on the west side of section 4, on the north side of the creek, is another marked unconformity between the saccharoidal sandstone and the underlying siliceous limestones. Large quantities of the saccharoidal sandstone occur from this point to the upper limit of the Silurian on the creek. It is an almost continuous ledge through the middle of section 4, forming the top rock of Mill Bluff just south of the middle of section 4, where, in a bed 10 to 25 feet thick, it rests unconformably on the underlying siliceous limestone.

In the ravine from the east in section 3 (18 N., 23 W.), the

marble is mostly concealed, and where exposed it is much disintegrated. The sandstone outcrops in a massive ledge on the south side of the ravine in the southwest quarter of section 3, with a dip of 8° to 10° north of east. In the short ravine in section 10, the southwest quarter, saccharoidal sandstone outcrops in a massive ledge 40 to 60 feet thick, forming a horseshoe curve near the mouth of the ravine with the watercourse in the middle, which forms a cascade in time of a freshet, but is dry at ordinary seasons. The marble outcrops in section 15 (18 N., 23 W.), the west part, at the spring on the east side of the wagon road, where it dips east several degrees, and is presumably close to the monoclinal fault mentioned above. Small exposures of the marble occur along the creek for half a mile or more above the spring, above which the Boone chert and limestone occur along the bottom of the valley.

The marble outcrop on the west side of Osage Creek is higher than on the east side, owing to a dip of the strata to the east; there is not as much marble exposed as on the east side and it does not occur so close to the creek. On the road from the creek to Piney post-office there is a small exposure in section 8 (18 N., 23 W.); only a few feet, however, are exposed, and that in but one place.

On Griffy Branch in 19 N., 24 W., sections 25 and 36, the marble is exposed in weathered ledges. It does not show on the wagon road but appears on both sides of the ravine south of the road and in the ravine from Crystal Mountain, where it outcrops in weathered ledges. In section 25 (19 N., 24 W.), the southwest quarter, on the north side of the tributary of Griffy Branch from Crystal Mountain, is a prominent unconformity between the saccharoidal sandstone and the underlying rocks. The sandstone is 50 feet thick and much brecciated at the bottom, large irregular pieces of siliceous limestone occurring in it. The marble outcrops on the hill above the sandstone mass, and from there to the head of the ravine at Crystal Mountain, more than a quarter of a mile; east of the sandstone mass the marble is concealed by broken chert. On top of Crystal Mountain, at the head of this ravine in section 26

(19 N., 24 W.), is a large quantity of quartz crystals in the Boone chert. These crystals occur in masses and in fissures in the chert, in some instances forming masses of several hundred pounds in weight, the separate crystals varying from microscopic ones to those half an inch or more in diameter.

West of Crystal Mountain the marble is in many places entirely concealed by the chert fragments, while in some places an occasional weathered ledge is exposed, showing its position and continuance. It occurs around the heads of Lundy's, Farmer's, and Lazy Coves to the north end of Pension Mountain, in 19 N., 25 W., section 3.

The marble outcrops in many places on Trigger Mountain in the north part of 19 N., 25 W., and along the ridge on the east side of King's River to Piney Creek, but no exposure of special prominence was observed.

Piney Creek.—Piney Creek heads in 18 N., 23 W., section 29, and empties into King's River in 19 N., 25 W., section 34. The Silurian rocks outcrop along each side of the creek from the mouth to 18 N., 24 W., section 14. At the top of the Silurian occurs a heavy bed of saccharoidal sandstone, which outcrops in an irregular, prominent, massive ledge at the water-mill in 18 N., 24 W., section 15, and on the lower part of Cedar Hollow in section 10. Below the mouth of Cedar Hollow the valley is narrow, the rocky bordering hills standing so close to the creek that there is practically no bottom land until near the mouth of the creek, where there are two or three farms. On the north side of the creek in 18 N., 24 W., section 9, is a marked unconformity between the sandstone and the underlying siliceous limestone.

The marble exposures on Piney Creek so far as observed have no marked peculiarities. In most places the upper part of the bed is concealed by the chert fragments, which in some places conceal the whole bed. The marble outcrops in low bluffs in 18 N., 24 W., section 14, on the north side of the creek; in section 15, on the south side of the creek, on the east side of the small ravine from the south, near the mill; in section 10 in Cedar Hollow; and in section 3, near the head of

Brush Creek. At the last locality, on Brush Creek, the marble is underlain by a thin bed of Eureka shale. The marble horizon lies so near the tops of the hills at the mouth of the creek, that it has nearly all disintegrated, leaving the thin bed of fragmentary chert resting directly on the Silurian rocks.

Dry Fork of King's River.—The marble outcrops on each side of Dry Fork from its junction with King's River to 18 N., 24 W., section 29, one mile above Omega post-office, and two small isolated areas occur further up-stream, one in section 31 (18 N., 24 W.), the other in 17 N., 24 W., section 3. In all the exposures the marble has a shelly fissile surface structure, and a reddish gray to chocolate color. It is underlain by a heavy bed of saccharoidal sandstone which is exposed in large areas nearly devoid of vegetation in section 30 (18 N., 24 W.), and in rugged bluffs along the stream in 18 N., 25 W., the outcrop being especially rugged at the mouth of the small tributary from the south known as Tar Kiln in 18 N., 25 W., section 26. The Boone chert extends as far as Dinsmore post-office, near the head of the creek; but the limestone of the chert bed outcrops for a quarter of a mile above the post-office, in one place being intercalated with the Batesville sandstone. The Batesville sandstone and accompanying shales outcrop for two miles or more south of the post-office. The Millstone grit occurs in a heavy bed on the tops of the hills.

There are several small outcrops of marble on the east side of King's River, south of Dry Fork but none of marked importance.

West side of King's River south of Rock House Creek.—The most southern outcrop of marble observed on King's River is at the base of the high bluff in 18 N., 25 W., section 32. It outcrops at the mouth of Lake Hollow in section 29, the southeast quarter. The lake from which this hollow takes its name is a small pond of water in the faulted area at the head of the hollow.

On Pine Creek in 18 N., 25 W., sections 29 and 30, and 18 N., 26 W., section 25, are large exposures of marble which are especially prominent in the ravine from the south in the east

part of section 25. The marble is underlain by a heavy bed of saccharoidal sandstone from which it is separated by a thin bed of Eureka shale.

The marble is exposed on the small tributary in 18 N., 25 W., sections 4 and 5, the outcrop at the mouth of the ravine being near the top of the hill, where it is much disintegrated; near the head of the ravine, the marble which is of finer quality, is at the base of the hill and is underlain by a thin bed of Eureka shale.

Rock House Creek.—One tributary of Rock House Creek heads at Swain Mountain, only a narrow divide separating it from Keel's Creek; another tributary heads southwest of Fancher post-office. There is a large exposure of Silurian rocks which extend to the tops of the hills at the mouth of the creek but occur at a gradually lower level in ascending the creek. The largest exposures of marble are near the heads of the many ravines, several small isolated areas occurring on the high points near the mouth of the creek. In 19 N., 26 W., sections 35 and 36, on the north side of the creek at the junction of the Swain Mountain and Ash Cave branches, is a prominent sandstone bed which at the eastern end shows false bedding and toward the west is massive, being 50 feet or more in thickness. On the south side of the creek opposite is a large sandstone prominence 50 feet in diameter and 30 feet high, surrounded by magnesian limestones.

In 19 N., 25 W., sections 5 and 6, on the road from Winona Springs to King's River, the St. Joe marble is 50 feet thick and outcrops for 150 yards or more with no overlying chert; it is underlain by two feet of Eureka shale, which is underlain in turn by three to four inches of reddish brown shaly sandstone (possibly the Sylamore sandstone) followed by magnesian limestone.

Keel's Creek.—Keel's Creek heads at Swain Mountain in the southwest part of 19 N.. 26 W., and drains part of four townships, 19 and 20 N., 25 and 26 W. The marble outcrops on both sides of the creek and in all the numerous lateral ravines. In Cedar Hollow and Greenwood Hollow the marble is exposed

in many places, but it is often concealed by the chert debris. In March, 1891, the marble was being quarried in two places in 20 N., 26 W., section 27,—one on the hill southeast of the lake, the other northwest of the lake,—for use in constructing the large archės on the boulevard from Eureka Springs to the Sanitarium. The marble, which resembles that at Eureka Spings, varies from a light pink to a reddish chocolate color, is but slightly fossiliferous and contains numerous small seams. Despite the seams, which mar its beauty, the stone is apparently strong and durable. At the breast of the artificial lake at the Sanitarium is an example of erosion in the Silurian strata, where the white sandstone forms a wall-like mass extending across the valley. That it is not a part of a continuous bed is shown by the occurrence of the siliceous limestones in place on either side. The sand apparently was deposited in a channel in siliceous limestone strata. A somewhat similar but less prominent exposure of sandstone occurs in the ravine from the south, about a quarter of a mile above the lake, while other more rounded and isolated exposures occur at different places in the hollow.

The marble outcrop extends up Keel's Creek as far as the old mill site in 19 N., 26 W., section 15, the southwest quarter, where it is succeeded by the overlying chert. In sections 15 and 10 a heavy layer of saccharoidal sandstone occurs underlying the marble.

The outcrops in Williams' Hollow in the east and northeast of townships 19 N., 26 W.; in 19 N., 25 W., section 7; and in 20 N., 25 W., sections 31 and 32, are similar to that on the main creek. The wagon road from Concord school-house to King's River, by way of Morris Hollow, crosses the high ridge in the northeast quarter of section 30 on the Silurian rocks through a gap in the Carboniferous rocks which outcrop on each side of the road.

West side of King's River below Keel's Creek.—The Eureka Springs-Berryville road, (the Keel's Creek road) crosses the marble horizon in 20 N., 25 W., section 19, but no marble is exposed on the road, being concealed by the chert debris. It

outcrops north of the road, and around the heads of the ravines at Grand View in sections 18 and 19. The "wire road" crosses the outcrop in section 18 (20 N., 25 W.), north of which in sections 18 and 7 the marble forms a low escarpment along the hillside.

On Cox and Roberts' Creek in sections 6 and 7 (20 N., 25 W.), and 20 N., 26 W., section 12, the finest outcrop is on the north side of the creek, where it is underlain by the Eureka shale. In sections 5 and 6 (20 N., 25 W.), a fine quality of magnesian limestone (" cotton rock ") is exposed.

The marble outcrops on the head of Bee Creek, 21 N., 25 W., sections 30 and 31, on the head of Brush Creek in section 20, and on Boat Mountain in sections 19 and 20, but none of the exposures promise a stone of any economic value.

CHAPTER XXV.

The Distribution of the St. Joe Marble—*Concluded.*

UPPER WHITE RIVER VALLEY.*

(Eureka Springs map sheet.)

General features of the upper White River valley.—White River heads in the southern parts of Madison and Washington counties, in the Barren Coal measures. As the strata have a general dip to the south, the stream cuts successively through the rocks of the Barren Coal Measures, Lower Carboniferous and Silurian; gentle folds in the strata, however, cause a little irregularity in this succession, so that there are isolated exposures of Silurian many miles above the point where the Lower Carboniferous first appears in the bottom of the valley. The Lower Silurian rocks, consisting of dolomites, cherts, and sandstones, have an exposure of nearly 400 feet in thickness, in townships 20 and 21 N., and the north part of 19 N. The most southern exposure of the Silurian rocks on main White River is at the confluence of that stream and War Eagle Creek. There are, however, several exposures on War Eagle Creek above this point. The Silurian exposure in the southern part of this area (township 18 N.) is marked by a heavy bed of massive saccharoidal sandstone, which outcrops in bold ledges along the streams. In the northern part of the area this sandstone is an insignificant bed but a few feet in thickness and totally lacking in some places. The dolomites are in some places very siliceous, and form terraced slopes, some of which are as regular as artificial ones, and are sometimes almost entirely barren of trees.

*Including the part of the White River basin between its headwaters and the point where it crosses the state line into Missouri. Nearly all of the west side of this part of the valley lies in Benton and Washington counties, and is described in the reports of those counties. Washington County, Vol. IV., 1888. Benton County, Volume II., 1891.

The larger part of the area north of the middle of township 17 N. is covered with the Boone chert of Lower Carboniferous age. The chert contains less limestone proportionally than it does in the regions further east, yet at several places within this area are exposures of limestone of fine quality.

The Eureka shale, which lies between the Silurian and the St. Joe marble at the bottom of the chert, occurs in a heavier bed in the upper White River valley than in any part of the region further east.

On the highest points of the watershed on each side of the valley are small, isolated areas of Batesville sandstone, a formation which is quite prominent south of the east-west fault that runs through township 17 N.

The part of White River between its confluence with War Eagle Creek and the state line is the crookedest part of its course in the state, unless it be that in the north part of Marion county, where it re-enters the state. A great similarity will be observed in comparing this part of its course with the lower course of King's River and the lower course of Buffalo, all three of which are in the same kind of rocks, namely, siliceous dolomites. King's River, however, while not less tortuous in its windings, differs from the other two in the more extensive erosion in its valley, which is shown on the map by the greater distance of the Carboniferous outcrop from the stream.

The marble throughout this part of the area is inferior in quality to that in the Buffalo River and Crooked Creek valleys. In fact, throughout the greater part of the area it is not, properly speaking, marble at all, yet there are numerous places where a fair quality of marble could be obtained, and many places where it will furnish a good building stone.

Haddock Creek.—From the head of Brush Creek in the King's River valley, 21 N., 25 W., the marble forms an irregular escarpment around the head of Owl Creek and along the south side of Haddock to the hills overlooking White River. In many places along Haddock Creek the marble bed is concealed by the overlying Boone chert, and on the north side of the creek near the head, the marble and the overlying chert have been

PIVOT ROCK NEAR EUREKA SPRINGS.

eroded away, leaving a much weathered remnant of the chert and marble bed on the hill nearer the river.

Leatherwood Creek.—On the lower course of Leatherwood Creek the hills are formed of dolomites and cherts of Lower Silurian age. Some of the dolomites furnish a beautiful and valuable building stone, which has been quarried at many places between Eureka Springs and the mouth of the creek.*

A small isolated area of the marble occurs on the hill between Leatherwood Creek and White River in 21 N., 26 W., section 17. A larger and finer exposure occurs on the east side of the creek in sections 16 and 21 (21 N., 26 W.), where the surface exposure shows a marble of as fine quality as any observed along Leatherwood Creek. The rock on the surface is not devoid of seams, but they are smaller and less numerous than in many other places, and the color is brighter. It outcrops at intervals to and around the heads of the numerous terminal ravines of both East and West Leatherwood Creeks. In many places it forms a prominent escarpment along the hillsides. In 20 N., 26 W., section 4, on the hill between East and West Leatherwood Creeks, is an isolated remnant of the marble ledge which is known as Pivot Rock. The rock has decayed more rapidly at the base than at the top, thus leaving a huge mass of many tons weight standing on a very small base only a few yards from the parent ledge. (See Plate XVII.)

About 200 yards southeast of Pivot Rock is another natural phenomenon known as the Natural Bridge, which consists of a large opening through a mass of saccharoidal sandstone, the bottom of which is brecciated. This sandstone and other masses east of it mark an unconformity in the Lower Silurian rocks.†

At Eureka Springs the marble is 200 feet above the railway station, and extends, at very nearly the same level, around the

*For further particulars on the dolomites, see pp. 115–125.

†Other similar instances of an unconformity in the rocks occur in the vicinity of Eureka Springs, such as Puzzle Rock west of West Leatherwood Creek in 20 N., 26 W., section 5, and at Oil Spring and along the creek near Sycamore Spring.

heads of the numerous ravines in the town. The most prominent exposures in the town are along Spring Street from Grotto to Basin Spring, in Little Eureka Hollow, on East Mountain and around the head of Mill Hollow, and Magnetic Hollow. It has been quarried at the following places mainly for use in building foundations and retaining walls: on Spring Street east of Grotto Spring; at the corner of Spring Street and the road to Crescent Hotel; at several points between Crescent and Harding Springs; on both sides of Little Eureka Hollow; on East Mountain and on the hill northwest of the depot. It has been quarried for lime on the north side of Dairy Spring Hollow on the hill opposite Dairy Spring. Owing to the fragmentary condition of the chert and the steep slopes, numerous and high retaining walls are necessary, in many places being required on both the lower and upper side of the street and at the rear of the houses. This work is facilitated in many places by running the street along the base of the marble so that the marble which is removed to make room for the house is sufficient to build the retaining wall in front of it, and the bed from which the marble is taken thus forms a natural wall behind it. Below the marble bed, the streets are on the Silurian rocks, over which but little chert occurs; above the marble bed the streets run up and down the hills so that retaining walls on the streets are needed only where they are winding.

The marble is also used for building the side walls of several of the stores on Mud Street, the basement of the Presbyterian Church, and of a number of dwelling-houses.

The color of the marble quarried at Eureka Springs is light gray and pink which deepens in some places to a light red, and in others to a dark red. None of the quarries have penetrated the marble bed to any considerable depth, but so far as observed, no marble has been quarried that is wholly free from seams, yet these are less numerous and prominent in the deeper exposures than on the surface ones. Despite the seams, the rock dresses readily and appears to make durable building stone. The seams, however, mar its value for ornamental pur-

poses, and to obtain in large blocks what can properly be called marble, it will be necessary to penetrate the beds to a greater depth than has been done so far. Small pieces of nice marble, obtained from the surface rock, have been used in ornamenting the Crescent Hotel, Grotto Spring, and in the manufacture of paper-weights, etc.

The marble is underlain by the Eureka shale,* which occurs, as a black, pyritiferous, argillaceous shale, in a bed from two to five feet in thickness; overlying which in some places is a green, fossiliferous shale containing much pyrite.

Section at Eureka Springs from the Crescent Hotel to the railway depot.

	Feet.
Boone chert	60
St. Joe marble	40
Green shale	1
Black shale (Eureka shale)	4
Saccharoidal sandstone	5
Concealed	54
Quartzose sandstone	3
Concealed	10
Saccharoidal sandstone	6
Concealed	3
Chert conglomerate	3
Concealed	6
Silico-magnesian limestone	4
Agatized chert	15
Silico-magnesian limestone	20
Concealed	10
Silico-magnesian limestone, alternating light and dark layers	16
Silico-magnesian limestone	25
Dolomite ("cotton rock")	25
Total	310

At some, possibly all, of the places marked concealed, magnesian limestone occurs, as it is found at the same level in the near vicinity.

It is an interesting fact that nearly all of the numerous springs in the town of Eureka Springs emerge at the same hori-

*It is from Eureka Springs that this bed of shale has been named by the State Geologist.

zon as the Eureka shale.* This is illustrated on the accompanying sketch (Plate XVIII). A few of the springs, as the Magnetic and some along Mud Street, have penetrated the Silurian rocks, but nearly all of the principal springs, as Dairy, Grotto, Crescent, Harding,† Sweet, Basin, Little Eureka, Spout, Arsenic, Oil, Mystic, and many others, emerge at the bottom of the marble bed on or in the shale. The explanation lies in the fact that the chert bed is very splintery and fragmentary on the surface and is in all places pervious to water; thus but little of the water that falls on the chert area flows off as surface water. The water, which contains more or less carbonic acid in solution, enlarges openings along the joint-planes in the limestone intercalated with the chert and in the St. Joe marble at the base. The Eureka shale is thus the first impervious stratum below the tops of the hills and on this, emerges nearly all the water that falls thereon. In the marble bed, no doubt, occur the reservoirs which feed the springs.

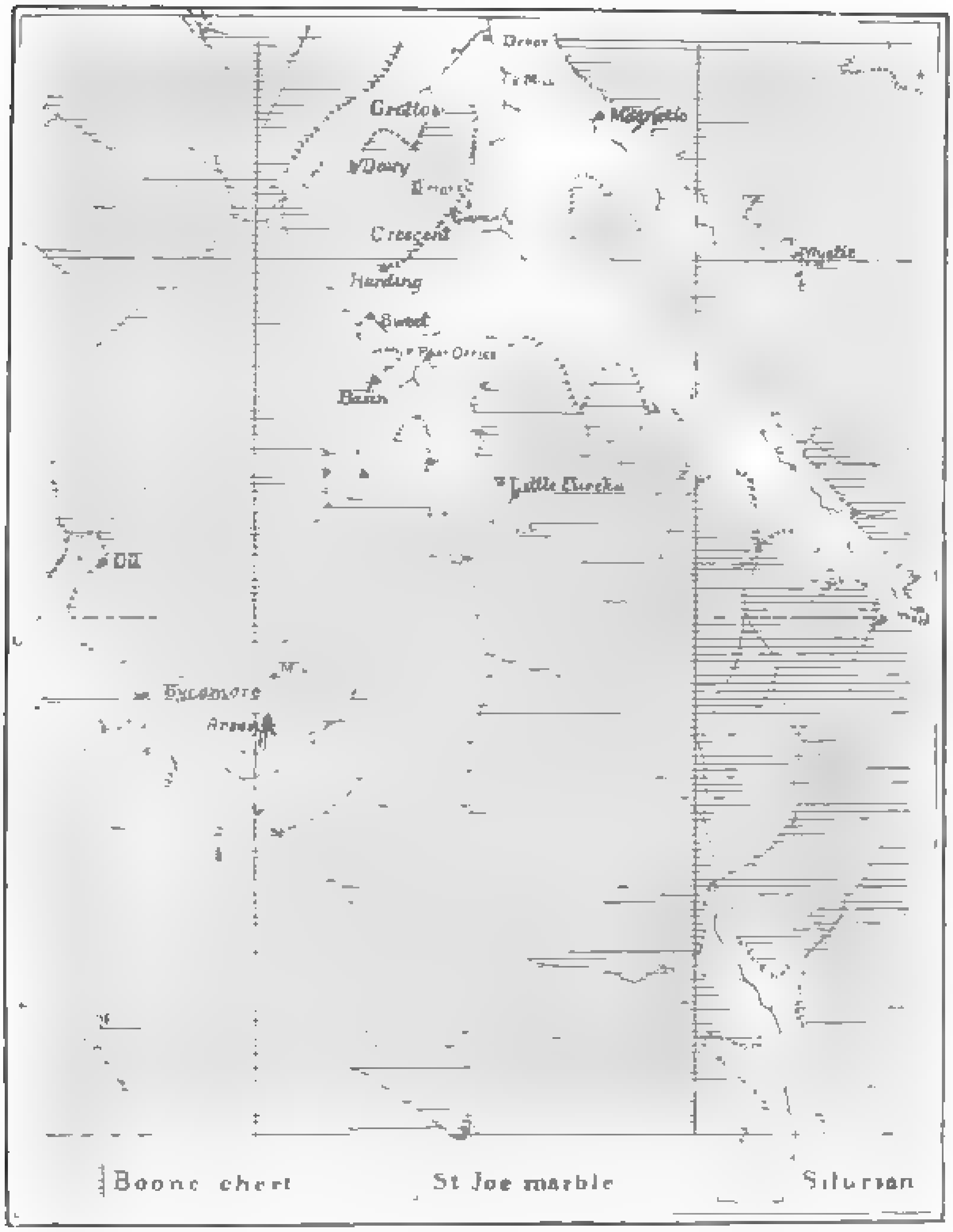
The onyx marbles found at and near Eureka Springs are described in the next chapter.

Between Leatherwood and Clifty Creeks.—On the east side of White River between Leatherwood aad North Clifty Creeks the marble forms a broken escarpment along the river hills and on the small tributaries known as Cliburn, Dick's and Honey Creeks. No outcrop of special prominence was observed in this area.

North Clifty and Big Clifty Creeks.—The Clifty Creeks derive their name from the cliffs along their courses, yet these cliffs are no larger or no more numerous than those on almost any other creek in North Arkansas. Both North and Big Clifty Creeks head in the chert-covered ridge which forms the divide between White River and King's River, a short part of the upper course of the different tributaries being in the Boone

*This is true not only at Eureka Springs but over nearly all the north part of the state. Even in the absence of the shale the springs emerge at the same horizon, namely at the base of the marble. The heavy bed of saccharoidal sandstone which in most places underlies the shale, or the marble in the absence of the shale, appears to be equally impervious to water.

†See Plate XIV. for illustration of bluff at Harding Spring.



MAP OF THE REGION ABOUT EUREKA SPRINGS
Showing the Influence of Geologic Structure on the Emergence of Springs.

chert, below which they cut through into the marble and the underlying Silurian rocks. The largest outcrops of the marble observed on North Clifty Creek are those in 20 N., 27 W., sections 28, 23, and 24, and those in 19 N., 26 W., sections 5 and 6. Probably the largest exposure on Big Clifty Creek is on the west side of the creek on the narrow ridge between the creek and the river. A heavy bed of saccharoidal sandstone underlies the marble in 19 N., 27 W., sections 13 and 14.

Little Clifty Creek—Little Clifty Creek consists of two main tributaries, one in 19 N., 27 W., the other in 19 N., 28 W. The marble occurs on each of them from the river to three miles or more above their confluence. Little marble is exposed on the lower part of the east tributary, but prominent ledges outcrop in section 17 and in the south part of section 18 (19 N., 27 W.). On the west tributary the finest exposures are in sections 22 and 14 (19 N., 28 W.), below the Van Winkle mill, where the marble is underlain by Eureka shale and saccharoidal sandstone.

War Eagle Creek.—The greater part of that portion of the War Eagle Creek valley which is shown on the accompanying map, is in the Boone chert. There are three exposures of the marble and underlying Silurian rocks in the valley, all of which mark the axes of low anticlines. The lowest exposure of the marble on War Eagle Creek is in 18 N., 28 W., where it outcrops on each side of the creek for six or seven miles, but so far as can be judged from a surface examination, none of it has any economic value. It is underlain by a bed of Eureka shale varying from ten to thirty feet in thickness. There is one small exposure of the underlying saccharoidal sandstone in section 16 (18 N., 28 W.).

The next outcrop of the marble is around the mouth of Stanley Branch in 18 N., 28 W., sections 12 and 13, where it is underlain by both the shale and sandstone, the shale, however, being an inconspicuous bed entirely concealed in places.

The next outcrop of marble met in ascending War Eagle Creek, and the largest exposure on the creek, occurs in 18 N., 26 and 27 W., and in 17 N., 26 and 27 W. Along the township line

between townships 17 and 18 N., it forms a bold escarpment not far above the creek where it is underlain by a few feet of black Eureka shale which is very pyritiferous and is separated from the marble by a thin siliceous layer containing black, earthy, ferruginous pebbles. The most promising outcrops of the marble in this area are those in section 5 (17 N., 26 W.), on the south side of the creek near the mouth of a small ravine along the Huntsville-Clifty road; and in section 10, the same township, on the north side of the creek at the crossing of the Eureka Springs-Huntsville road. In both places red, pink, and chocolate colored marbles appear, some of the layers being very fossiliferous and susceptible of a fine polish. On the surface it contains many seams and no opening has been made at either place to show the texture of the interior of the bed. The most southern outcrop of the marble on War Eagle is in 17 N., 26 W., section 13, at the ford of the Huntsville-Alabam road. At many places down-stream from the last mentioned point, the marble horizon is concealed by debris from the overlying chert and in some places is apparently below the water-level.

On the north side of Kennedy Branch east of the Eureka Springs-Huntsville road in section 15 (17 N., 26 W.), is an outcrop of oōlitic limestone of fine quality, which would make an excellent building stone.*

White River above its confluence with War Eagle Creek.—At the confluence of White River and War Eagle Creek is an exposure of the St. Joe marble and the underlying Silurian rocks which extend up White River about two miles above the confluence of the two streams. The lowest rock exposed is a massive bed of saccharoidal sandstone sixty to seventy feet thick overlain by the Eureka shale which here attains a thickness of fifty feet or more. The St. Joe marble which overlies the shale, is represented by a bed of disintegrating, lumpy, gray limestone, which has no economic value unless it be for lime burning, and which is in no sense a marble.

The marble does not occur on White River above this point.

*See pp. 99 and 107 for analysis and description.

For many miles the course of the river is through the Boone chert formation, which finally dips beneath the water-level and is succeeded by the overlying shales and sandstones of Lower Carboniferous age.*

Butler Creek.—Butler Creek heads in the state of Missouri and drains parts of townships 21 N., 26 and 27 W., in Arkansas. The marble outcrops on the hills on each side of the creek, on the top of the hills on the lower course, and gradually nearer the base of the hills towards the head of the creek. The creek and the railway cut through the marble bed in the bottom of the valley, not far from Seligman, Missouri. In all the exposures observed the marble is full of seams, and of a pale red or gray color. The surface rock might be used for lime burning, but it lacks the necessary texture to give it any value as a marble.

Spider and Indian Creeks.—The marble outcrops on both Spider and Indian Creeks, but no outcrop promising a stone of any economic value was observed. Indian Creek is remarkable for the deep narrow gorges through which it and its short tributaries flow. The bordering hills are higher than on the east side of the river. Several heavy isolated masses of Lower Carboniferous sandstone occur, through which and the underlying chert the streams cut with remarkably swift descent deep into the Silurian rocks.†

*For description of this part of the valley, see report on Washington county, Vol. IV., 1888.

†For description of the west side of White River above Indian Creek, see report on Benton county, Vol. II., 1891.

CHAPTER XXVI.

OTHER MARBLES FOUND IN ARKANSAS.

While the two beds of marble described, the St. Clair and the St. Joe, include the great part of the marbles of the state, there are a few other varieties of some commercial importance which do not occur in either of these beds. Among them may be mentioned: the limestone of the Boone chert, which in some places furnishes a gray marble; onyx marble, which is obtained in many of the caves; marble in the Archimedes limestones; and black and yellow varieties which have been found.

THE GRAY MARBLE OF THE BOONE CHERT.

Paleontologically the St. Joe marble is part of the Boone chert bed, but as has been already stated (p. 254), it includes only that part of the formation which lies wholly beneath the chert proper. Overlying the St. Joe marble, and separated from it in most places by more or less chert, are beds of gray crystalline limestone, which in many places would furnish a handsome and durable stone.

At many points it will compare favorably in texture and composition with either the St. Clair or the St. Joe marble, but as it lacks the bright colors, it is less valuable for ornamental purposes.

The finest quality occurs in the central part of the marble area, in Searcy, Marion, Boone, and Newton counties, where it is all of a light gray color, and in many places has fossil remains, the abundance of which compensate, in a measure, for the lack of bright color.

Mr. Nick Miller of Harrison has worked a number of nice tombstones from this chert marble, examples of which may be seen in the cemetery at Western Grove and at many other places through the central marble area. The Arkansas Marble

Company has laid claims, in 16 N., 18 W., section 13, on Mill Creek, two miles west of St. Joe, on a fine exposure of this rock, the analysis of which shows it to be a remarkably pure carbonate of lime.

Analysis of gray marble from Mill Creek, Searcy county.

	Per cent.
Lime (CaO)	56.14
Magnesia (MgO)	trace
Ferric oxide (Fe_2O_3)	.06
Potash (K_2O)	.12
Soda (Na_2O)	.08
Loss on ignition (CO_2, etc.)	43.77
Residue insoluble in acid	.30
Total	100.47

As far as chemical composition is concerned, the stone, as shown by analysis, is all that could be desired; not a trace of alumina could be found, and the other impurities combined scarcely exceed one half of one per cent. The stone is coarsely crystalline, takes a good polish and dresses easily. It is softer and more easily wrought than the St. Joe marble, but is inferior to it in color and brilliancy of polish.*

The oölitic variety of the chert limestone, which occurs near Batesville, has been used for monuments, but its dull gray color, its lack of fossils and the presence of amorphous material, which prevents it from taking a bright polish, make it unattractive for ornamental purposes. However, as a building stone, it is superior to the more highly crystalline varieties.†

ONYX MARBLE.‡

In numerous caves and interspersed through the limestone beds throughout North Arkansas are large bodies of traver-

*For further description of this stone and tests made of it, see p. 99.

†For notes on the distribution and uses of the chert limestone for building purposes and for lime-making, see Chapter VII.

‡Onyx is properly a form of silica, and the stalagmitic marble called onyx or Mexican onyx, is carbonate of lime and properly speaking not onyx at all, but from its banded structure and the brilliant polish it receives it is so called, and the name is now so common in the markets that it may be regarded as fixed, although stalagmitic marble or travertine, which it really is, would be a more appropriate name for it.

tine, or crystallized lime carbonate, deposited from solution, which in many places would furnish handsome marble. It has the same origin and belongs to the same class of marbles as Mexican onyx, Oriental Alabaster, Egyptian onyx,* etc. Not all the deposits of travertine will furnish equally good marble; in fact, in many places it is practically valueless for marble, as the stone is too coarsely crystallized and any attempt to work it into desired shapes causes it to crumble into separate crystals. It is only in deposits in which the texture of the stone will permit it to be dressed readily into the desired forms that it acquires value as a marble.

Hardness is another property on which the value of an onyx marble depends, as, other things being equal, the harder the stone the more brilliant polish it will take. As stated elsewhere in this volume (p. 14), the lime carbonate under different conditions crystallizes in two distinct mineral forms, namely, calcite and aragonite; of these, aragonite is the rarer and the harder of the two and being harder it will take a more brilliant polish than the softer calcite. The true Mexican onyx is said to be aragonite; however, a great many, probably most of the stalagmitic or onyx marbles are calcite. Several varieties of the onyx marbles from North Arkansas were tested and proved to be calcite.

Another important property upon which the value of onyx marble depends is color. The most highly prized varieties are the clear, bright, translucent ones, or those with bright colored bands, while the least sought are those with pale dull colors. None of the onyx marbles of Arkansas, so far as observed by the Survey, are quite as translucent or as brightly banded as the finest qualities of the Mexican stone, yet much of it is very handsome, works easily, takes a brilliant polish and will no doubt command a good price in the market; further research may show even finer qualities.

Near Eureka Springs it is obtained from two caves in the siliceous limestones of Silurian age. One of the caves from which the largest quantity has been obtained is on the east

*See pp. 45, 175, 194, and 204.

side of the railway, one mile north of the depot. Formerly slabs of the "onyx" were sawed from masses in the cave and let down on a truck over a wooden tramway to the wagon road at the foot of the hill. Slabs containing several square feet of marble were obtained and hauled by wagon to Eureka Springs, where most of the material was made into paper-weights, clocks, scarf-pins, penholders, etc., and sold as "Eureka onyx." No stone was taken from the cave in 1890.

Another cave from which considerable quantities of onyx marble have been taken is the one near Gaskin's Switch, four miles from Eureka Springs. In this cave large stalagmitic boulders occur, mixed with the clay in the bottom of the cave; in one place a shaft has been sunk 35 feet, in which it is reported that clay containing numerous boulders of "onyx" extended to the bottom of the shaft. Like that from the cave above mentioned, the onyx marble from Gaskin's cave has been manufactured into ornaments and sold at Eureka Springs.

In 20 N., 17 W., section 14, the northeast quarter, in the siliceous limestones of Silurian age, north of the Carboniferous area, is a cave from which A. L. Dirst, of Dodd City, has sent samples of onyx marble to dealers in Chicago and St. Louis, from whom he received favorable reports. It occurs in white, cream, red, and yellowish brown colors and closely resembles that used at Eureka Springs. Larger quantities of the stone are exposed to view in Mr. Dirst's cave than in either one of those at Eureka Springs, and apparently slabs four or five feet square or even larger could readily be obtained. It is a beautiful stone and will doubtless be highly esteemed as soon as attention is attracted to the extent of the deposit.

At the copper mine on Tomahawk Creek, 16 N., 16 W., section 6, small pieces of banded onyx marble have been found imbedded in the clay in which the copper ore was found. It lacks the hardness and translucency which would give it much value.

The Survey has received samples of beautiful brown onyx marble from Sharp county, but nothing has been learned of the extent of the deposit. Other deposits from which sam-

ples have been taken and which promise large quantities of fine stone are reported to occur in the southern part of Baxter county; in Marion county, northwest of Oakland; on Water Creek in Marion county; and on Livingstone and North Sylamore Creeks. It is probable that many valuable deposits of onyx marble will be developed in the localities named and elsewhere throughout the limestone region of North Arkansas.

So far as known all the onyx marbles of any value occur in the rocks of Lower Silurian age—the oldest rocks exposed. The caves are even more numerous in the Lower Carboniferous rocks than in the Lower Silurian and they contain large quantities of calcite, but it is too crumbling and shelly to have any value for marble.*

ARCHIMEDES MARBLE.

In many places the Archimedes limestone is highly crystallized and very fossiliferous, but in most places it has a loose shelly texture. Where it can be found sufficiently firm and strong it makes an attractive marble. The finest quality noted was taken from Mr. Gourds' well, near Salado Creek, in the southern part of Independence county. This variety has a firm, even, homogeneous texture, dresses easily, has an oōlitic appearance, takes a fine polish, has a light color on a broken surface and a dark color on a polished surface.

BLACK MARBLE.

A sample of a compact, fine-grained, black marble, having a brilliant polish, was presented to the Survey by Mr. Somers, of Sylva, Marion county. Mr. Somers states that it came from near Buffalo River, in the southern part of Marion county, but that it does not occur in sufficient quantity or quality to have any economic importance. It is a thin bed, in thin layers, and contains nodules of black chert.

*The caves in the Boone chert formation are very numerous and extensive, some of them being several miles in length. The Diamond Cave, near Jasper, Newton county, is remarkable for the abundance of pretty calcite formations contained therein. In the abundance, variety, and beauty of the crystals, this cave surpasses any other in the state.

It is reported that black marble has been shipped from the southern part of Independence county. Dr. Owen, a former State Geologist, says* of this black limestone at Oil Trough ridge, in the southern part of Independence county, that it "is of a fine black color, and is capable of receiving a polish, so that, if it can be quarried in sufficiently large slabs, free from cracks, imperfections and flaws, it may be employed for mantel-pieces and other ornamental inside work. For outside work, I fear it will be too liable to crack and split by the influence of the sun and atmospheric agencies." Prof. E. T. Cox says† of limestone at the same place: "One layer, full of entrochites, is hard enough to take a polish, and the fossils generally showing white on a black ground, it will make a handsome marble for ornamental purposes."

The present Survey has found black, compact limestone, probably the marble mentioned by Owen and by Cox, along the highlands south and west of the Oil Trough bottom. It has been noted in 11 N., 5 W., section 13, and extending thence along the foot-hills into section 18 of the same township and range, and east into 11 N., 4 W., section 18. East of the last point it was not traced, but it probably occurs at intervals as far as Grand Glaise, on the railway. This rock is not often exposed in considerable quantities, but is usually concealed by black soil. It is a compact rock, and is affected by weathering influences only on the immediate surface.

Black marble is reported to occur in Wiley's Cove, but was not examined. An impure black limestone occurs in places in the Fayetteville shale in Independence county, which may furnish a marble in places.

YELLOW MARBLE.

Some pieces of a handsome yellow marble, said to have come from Jimmy's Creek, in Marion county, were seen at Yellville. On visiting that locality, the Survey was informed that the sam-

*A Geological Reconnoissance of the Northern Counties of Arkansas, by Dr. D. D. Owen, 1858, p. 35.

†A Geological Reconnoissance of the Northern Counties of Arkansas, p. 218.

ples came from the bottom of a mining shaft, which was at that time filled with water. The samples were smooth, compact, and fine-grained, resembling the Sienna marble in color; it was slightly dendritic, and one piece had a dark red band half an inch wide running through it.

A unique yellow marble, very similar in appearance to the one above described, is on exhibition in the office of the St. Louis, Iron Mountain and Southern Railway, in Little Rock, and is marked as coming from Sister Creek, Ark.

CHAPTER XXVII.

QUARRYING.

Wood, which has been used so extensively in all kinds of buildings in the rapid growth of American cities, is now rapidly being replaced in public buildings, business blocks, and even in the finer residences, by safer, and in other respects preferable materials. Such fierce fires as those which destroyed large parts of Boston, Chicago, and Seattle in a few hours, tend to hasten the use of materials less inflammable than wood. The chief structural materials used in place of wood are brick, stone, and iron. Of these brick, on account of its cheapness, is used more extensively at present than either of the others. To be convinced of the superiority of stone over brick or any other material for architectural beauty, one only needs to compare buildings made of these separate materials. The only reason why stone is not more extensively used is that it costs more than other materials, and the reason for its greater cost lies in its quarrying, cutting, and transportation, for the supply is practically inexhaustible, and has little or nothing to do with cost. For the more extensive use of stone, and hence greater improvement in our architecture, we must, therefore, look to the improvements and prosperity of the quarry industry.

History.—Quarrying is one of the oldest of industries. The pyramids and obelisks of Egypt, the great Chinese wall, and the architectural remains of Greece and Rome show that quarrying and handling of stone were carried on many centuries ago, on a larger scale even than at present, for there are no stone structures of the present century which compare in magnitude with some of those mentioned.

While in recent years machinery has been extensively introduced into quarrying operations, it appears that less improvement has been made in quarry methods than in almost any

other industry. The hand drill, or jumper, so largely used in the quarry operations of the present day, has been in use from time immemorial. However, there is no evidence that the ancients had any such improvement over this method as modern quarrymen have in steam drills, and channeling and sawing machines.

The ancient Peruvians are said to have split the stone by first heating it with burning straw and then dashing cold water on it. Expensive and injurious to the stone as this method is, it is not more so than that used in Massachusetts in the early history of our country, in which the stone was first heated by building a fire around it and then broken by dropping upon it heavy iron balls from a considerable height.*

In Finland it is said† that even at the present day, the stone is split from the bed by drilling a series of holes along the line of the desired break, filling them with water, plugging tightly, and allowing the water to freeze, the expansion of which splits the rock. Blocks of 400 tons weight are said to be broken out in this way; but the operation must necessarily be a slow one, and not practicable in a warm climate.

Another method consists of plugging the holes with dry wood and then saturating the plugs with water; the expansion of the wet wood forces the rocks asunder.

The following is a chronologic arrangement of the growth and development of quarrying methods:‡

1. The mallet, chisel, and drill, have been in use from very early times.

2. Saws for cutting stone were used as early as 350 B. C., according to Pliny, who says:|| "This (the cutting of marble) is done by sand, but appears to be done by iron, as the saw

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*Smithsonian Report, 1886, Part II., p. 315.

†Grueber, Die Baumaterialien-Lehre, pp. 60, 61, quoted from G. P. Merrill in Smithsonian Report, 1886.

‡This chronology is compiled from various sources, mostly from Prof. H. M. Seeley's article on Development of Machinery in the Papers and Proceedings of the Middlebury Historical Society, Vol. I., Part II.

||Pliny, Naturalis Historia, 36, 51.

running in a very narrow groove cuts by rolling the sand in its motion."

3. Sawmills for sawing stone by water-power were used in Germany in the fourth century.

4. Long toothless saws were used by Misson, inspector of the Pyrenees quarries, for sawing blocks of marble from the quarry, before A. D. 1700.*

5. Two or more saws stretched in a frame, forming a gang, were figured by Leonardo da Vinci (ob. 1519).†

6. No record of the first use of gunpowder for quarrying can be found, but it was possibly during the sixteenth or seventeenth centuries.

7. Sawing by water-power was re-invented by William Colles, Kilkenny, Ireland, 1730.

8. Sawing and polishing by water-power were used in England in 1748.

9. Planing machine, Chas. B. Boynton, West Stockbridge, Massachusetts, 1836.

10. Percussive rock drill, J. J. Couch and others, 1849.

11. Diamond drill, used in England and France about 1850.

12. Channeling machine, George J. Wardwell, Rutland, Vermont, 1863.

13. Diamond saw used at East Canaan, Connecticut, 1876.

14. Gadding-machine, the bar channeler, and the direct acting channeling machine, where the gang of chisels is directly connected with the piston rod of the engine, W. L. Saunders, New York, 1883.

Hand drills.—Formerly all the drilling was done in the quarry by the hand drill or jumper‡ of which there are three kinds:

1. A short drill which the workman takes in one hand and strikes with a hand-hammer held in the other hand.

2. A longer, heavier drill, which is held by one workman

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*M. Felibieu (ob. 1687), quoted by Chambers' Cyclopedia, 2d ed., London, 1738.

†Clarence Cook, in Scribner's Monthly, Vol. XVII., p. 337.

‡The term jumper is limited by some writers to the churn drill, those used with a hammer being called hand drills.

and struck with a heavy striking hammer by another workman, there being frequently two strikers to one drill.

3. A long heavy drill known as the churn drill, which is used without a hammer, and is operated by the workman standing erect, lifting it, and bringing it down forcibly into the drill hole between his feet.

As in most of the other industrial operations, where the work is carried on extensively, it is found to be economical to substitute some mechanical force for hand labor.

PERCUSSIVE DRILL.

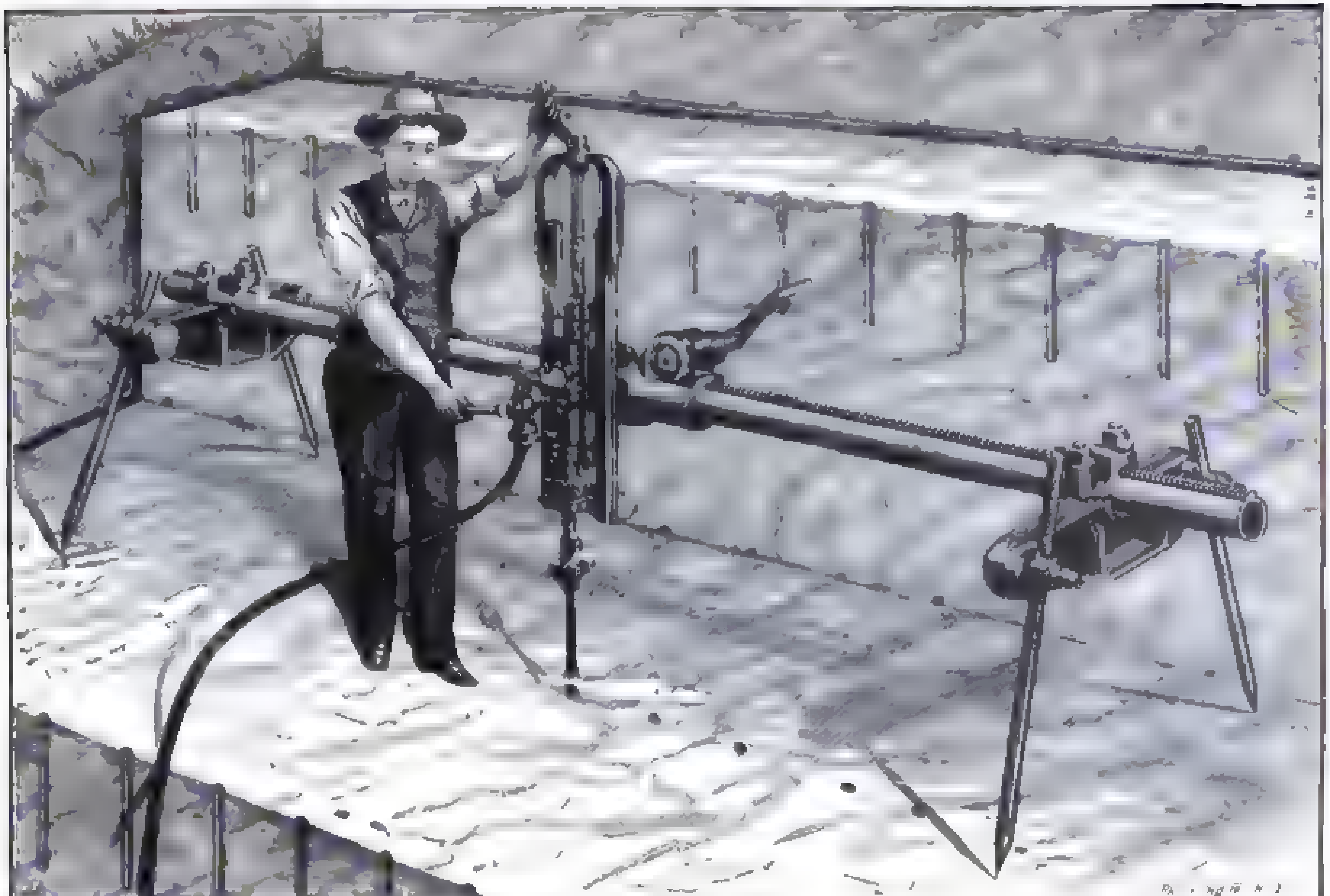
*History of the rock drill.**—In 1863 a drop-drilling machine was used in Germany, of which it is stated that " with ten blows it could sink a hole one and one-half inches deep, and a hand's breadth wide and long." In 1803 a machine was made at Salzburg, which was said to be "quicker than a miner." In 1849 J. J. Couch, of Philadelphia, patented a percussive rock drill in the United States. A little later in the same year Joseph W. Fowle, of Boston, patented a drill which was the first to have the drilling tool attached directly to the engine, or to a prolongation of the piston rod. Since that time Burleigh, Ingersoll, Wood, Githers, and Sergeant have made many improvements on the drill patented by Fowle.

The Mining Magazine briefly describes a rock drill patented in January, 1852, which claims a saving of at least 50 per cent. as compared with hand labor. It is not a percussive drill, however, but consists of a drill spindle, which is drawn up between two grooved wheels, and allowed to drop when at the proper elevation.†

The power.—In the larger quarries the percussive drill is now used almost exclusively. The power may be furnished by steam, compressed air, or electricity, the first being the one most commonly used; the last two are best adapted for min-

*Based largely on various papers and personal letters by Prof. W. L. Saunders, of New York City.

†Mining Magazine, N. Y., 1854, Vol. III., p. 227. Another interesting drill is described in the same magazine, Vol. I., p. 205.



INGERSOLL DRILL MOUNTED ON QUARRY BAR

ECLIPSE ROCK DRILL MOUNTED ON TRIPOD

ing or underground work, where the escaping steam is objectionable, or on steep cliffs or other places, where the power is to be conveyed a long distance, and they may be used to advantage where there is in the vicinity abundant water-power which it is desirable to utilize in quarrying. The electric drill is a comparatively recent invention, and has not yet come into general use.

The mounting.—There are several different ways of mounting the drill. The tripod as shown on Plate XIX., is the more common method, for being adjustable it can be arranged to cut perpendicularly, horizontally, or inclined at any angle desired. It is used in quarries where the surfaces are irregular or where the quarrying is done by blasting. One of the modifications of the tripod mounting is the lewis-hole tripod in which the center bars are elongated, and the front one perforated by a slot, which allows the drill clamp to move a few inches, so that three holes may be drilled and broached without moving the tripod.

The drills are frequently mounted on a column for use in a tunnel, drift, or mine. Plate XX. shows a drill mounted on a quarry bar, a mounting that is becoming more common in quarrying dimension stone. It is adapted to drilling a series of holes where perfect alignment is essential. In the figure it is set for drilling vertical holes, but can as readily be used to drill horizontal ones or those at any desired angle. It can be used as a substitute for a channeler by drilling the holes close and then substituting a broach for the drill and breaking down the intervening walls. After the tripod it is the most useful form of mounting.

Another form of mounting much used in marble quarries is shown on Plate XXI.; when so mounted it is called a gadding-machine, and is used for putting a series of holes on a true line for the insertion of wedges to break the stone into blocks. It is used in connection with the channeling machine in what is called "lofting" or breaking from the floor of the quarry into the cut made behind, and for putting a series of horizontal holes into the side of the bench for breaking the stone into

sections. The drill is pivoted to a saddle which can be raised or lowered on the standard, and the standard can be raised or lowered, thus permitting a series of holes at any angle on the bench or face of the quarry which enables the operator to readily follow the "riving bed" whatever be the dip of the rock. It can also be used to drill perpendicularly into the floor or roof of the quarry.

The drill bits.—In hand drills the single edge bit is always used. It is commonly tapering and the softer the stone the sharper the bit can be made. In sandstone the straight blunt edge is preferable to a sharp tapering one, because the drilling is done by crushing or loosening the grains, while in marble and limestone the stone must be cut, and for cutting a sharp bit is required.

The force used in the percussive drill is so great that single edge bits will not stand, and it is better to distribute the force of the blow over a larger surface on the drill bit than to decrease the force. The most common forms of bits used in percussive drills are shown in the accompanying figure; of these the bit, having a +, or plus-shaped, cutting

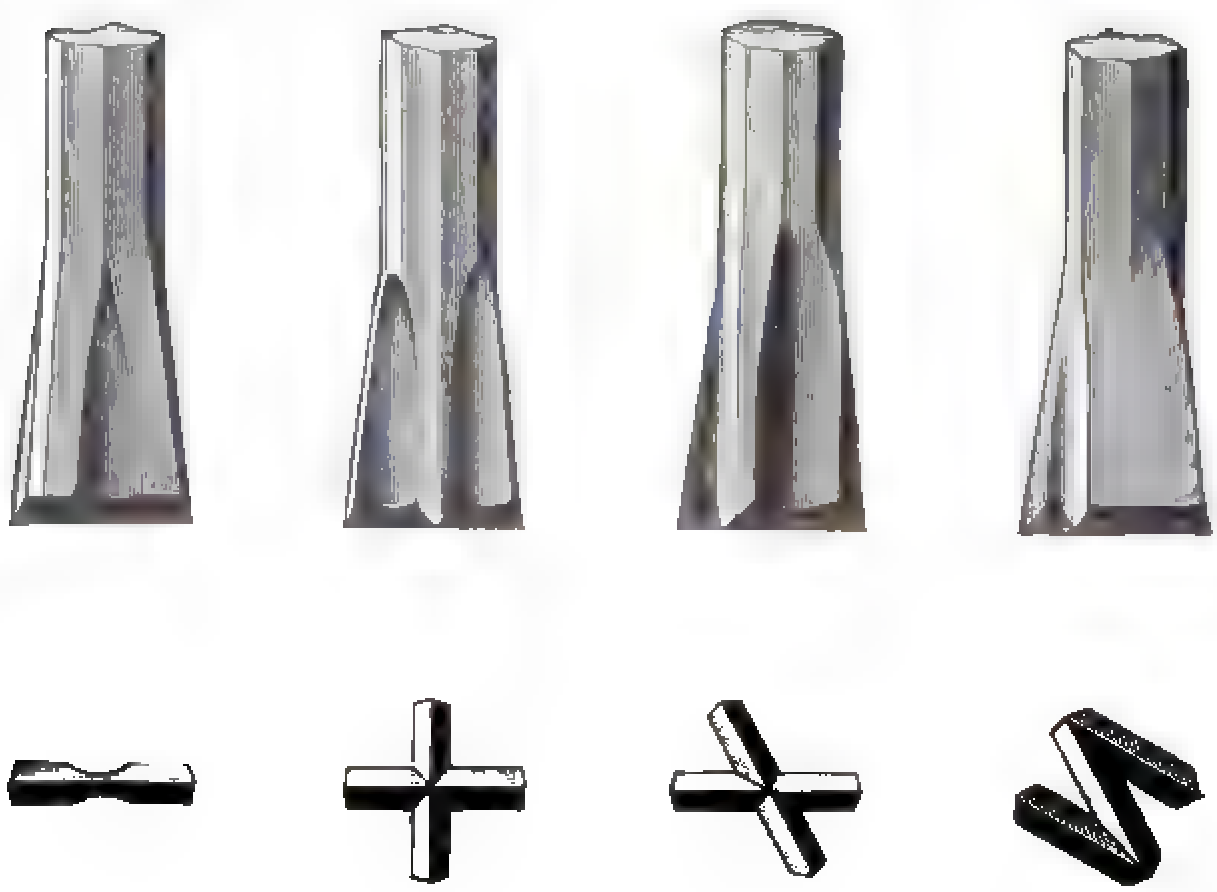


FIG. 7.—*Common forms of percussive drill bits.*

INGERSOLL GADDING MACHINE AT WORK IN A MARBLE QUARRY.

edge, is the one preferred in all rocks where it can be used, as it is more easily dressed by the blacksmith. But the X-shaped bit can be used satisfactorily in rocks where the + bit cannot. The Z-shaped bit is used to some extent in soft rocks. Where the single edge bit is used, it is customary to groove it in the center (as shown in the illustration) for the purpose of aiding it to discharge the cuttings.

Points to be observed in selecting a rock drill.—In his work on coal mining, André states concisely the requirements of a good rock drill as follows:

1. A machine rock drill should be simple in construction, and strong in every part.

2. It should consist of few parts, and especially of few moving parts.

3. It should be as light in weight as can be made consistent with the first condition.

4. It should occupy but little space.

5. The striking part should be relatively of great weight, and should strike the rock directly.

6. No other part than the piston should be exposed to violent shocks.

7. The piston should be capable of working with a variable length of stroke.

8. The sudden removal of the resistance should not be liable to cause any injury to any part.

9. The rotary motion of the drill should take place automatically.

10. The feed, if automatic, should be regulated by the advance of the piston as the cutting advances.

Rate of cutting.—Letters of inquiry have been sent to some of the leading marble and limestone quarrymen in the United States, asking the kinds and the rate of cutting of drills used in their quarries. The replies of such as responded are tabulated below, where it will be seen that the rate of cutting in marble and limestone varies from 100 to 200 feet per day of 10 hours, which includes the time used in moving the drill.*

*The rate of cutting will vary with the size of the drill hole, which is not taken into account in the following table.

One quarryman in comparing the steam drill with the hand drill in "plug and feather" work, says: "The steam drill cuts from 370 to 468 seven-inch holes in 10 hours, averaging 434 per day for two weeks, while a gang of men average about 23 holes of the same depth per man in 10 hours." Another comparison in blue-stone gives more than 50 feet per day to the steam drill and 7½ feet per day for one man. We frequently hear of much more rapid drilling than that given in the accompanying table, but these figures are all direct from the quarrymen and represent actual rates of cutting in various limestone and marble quarries.

Rates of drilling in different limestones.

Company.	Kind of stone.	Kind of drill.	Drilled in ten hours.
Sheldon Marble Co., W. Rutland, Vt...	White marble......	Ingersoll, Diamond.	150 feet.
Gross Bros., Lee, Mass.	Marble.............	Ingersoll, Diamond.	200 feet.
Perry Bros., Ellettsville, Ind........	Oölitic limestone ...	Ingersoll	300, 8-inch holes.
C. W. Babcock, Kasoto, Minn	Limestone.	Ingersoll	1 inch in two minutes.
St. Lawrence Marble Co., Gouverneur, N. Y.'..........	Dolomite (marble)..	Ingersoll	100 feet.
California Marble & Building Stone Co., Colton, Cal......	Dolomite (marble)..	Rand	128 feet.
Inyo Marble Co., Inyo, Cal..........	Marble............	Ingersoll	80 to 100 feet.

The diamond core drill.—The diamond core drill consists of an iron tube which has the bottom set with bort or black diamonds. They are made of different sizes; some are run by hand, others by horse, steam, or water-power. By means of these drills sections of the rock of any desired diameter and length can be obtained. The rate of drilling with them depends upon the size of the drill, the power used, and the nature of the rocks. A fair average in marble is from ten to fifteen feet per day by hand power, twenty feet and upwards with horse or steam power. Steel teeth are sometimes substituted for the diamonds.

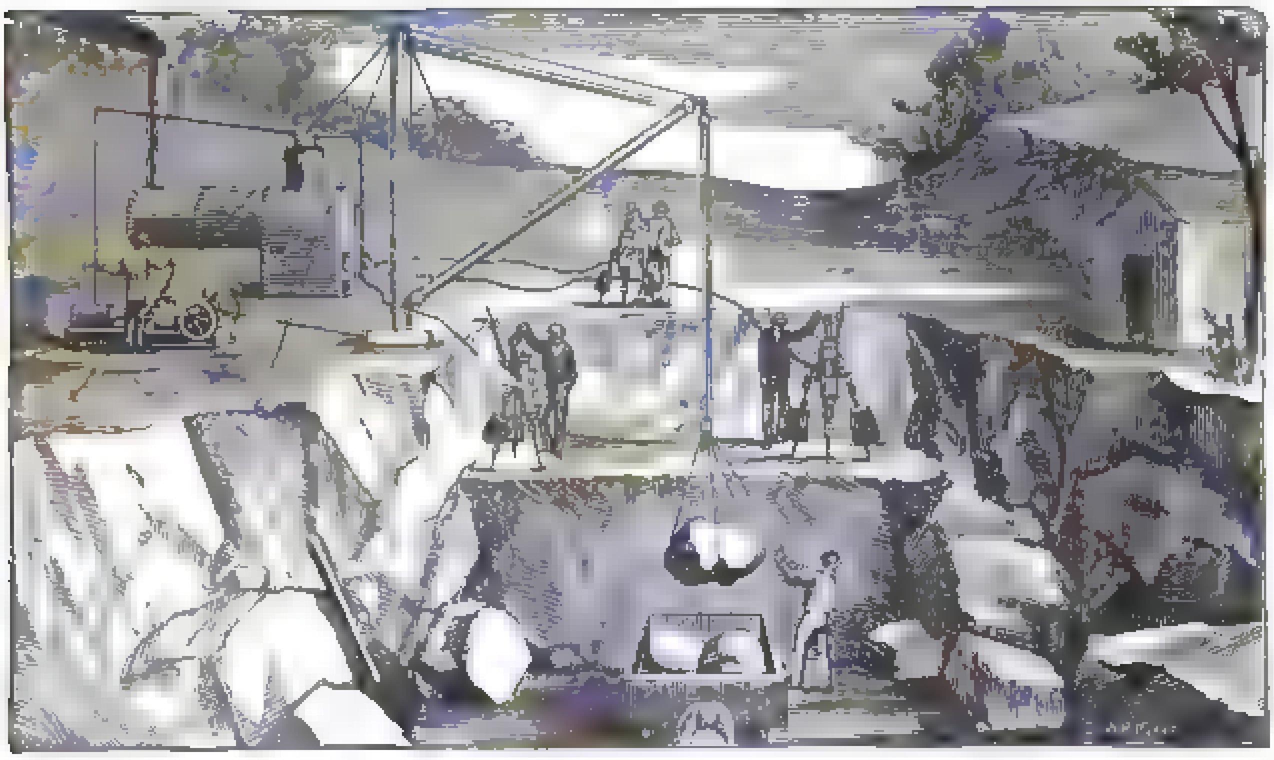


FIG. 8.—*Rock drills with attachments at work.*

CHANNELING MACHINES.

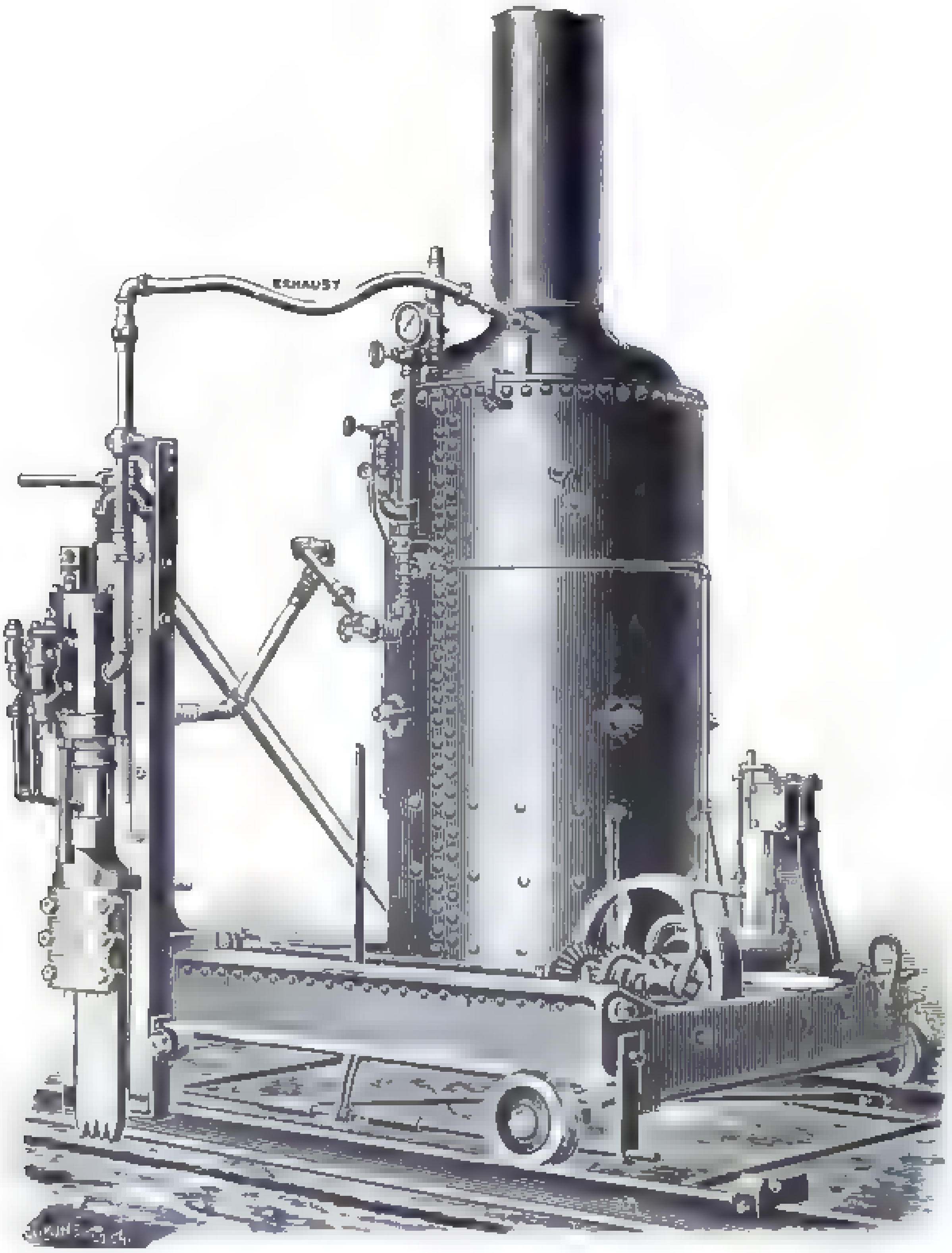
Varieties of channelers.—George J. Wardwell of Rutland, Vermont, invented and constructed the first channeler in 1863, and this first machine was in almost constant use for more than twenty years. Two kinds of channeling machines are now in use; the single gang machine, which cuts on one side only, and may be made to cut either a vertical channel or one inclined at any angle down to 45 degrees; and the double machine (Plate XXII.), which cuts a channel on each side, and is made of two widths, with channels four feet one inch or six feet seven inches apart. A special machine is made for use in sandstone quarries. One of these channelers is practically a locomotive engine, which moves back and forth over a track laid on the quarry floor and can be reversed at the ends without stopping. The double machine, shown on Plate XXII., carries on each side a gang of drills or cutters composed of five steel bars from seven to fourteen feet long, which are raised and dropped by a lever and crank arrangement. They cut, moving in either direction, can be reversed without stopping, and strike, it is claimed, 150 blows per minute on each side, feeding forward half an inch at each stroke, and cutting from half an inch to an inch at each passage.

The Ingersoll channeling machine differs from the Wardwell in several particulars, the most marked difference being that it is direct-acting, that is, the gang of cutters is attached rigidly to the piston and the blow is dealt directly by steam pressure in the cylinder. It can be adjusted to cut forward, backward, or at any angle, and it can be used not only for cutting channels in the quarry floor at any angle, but can also be used for making horizontal or side-hill cuts.

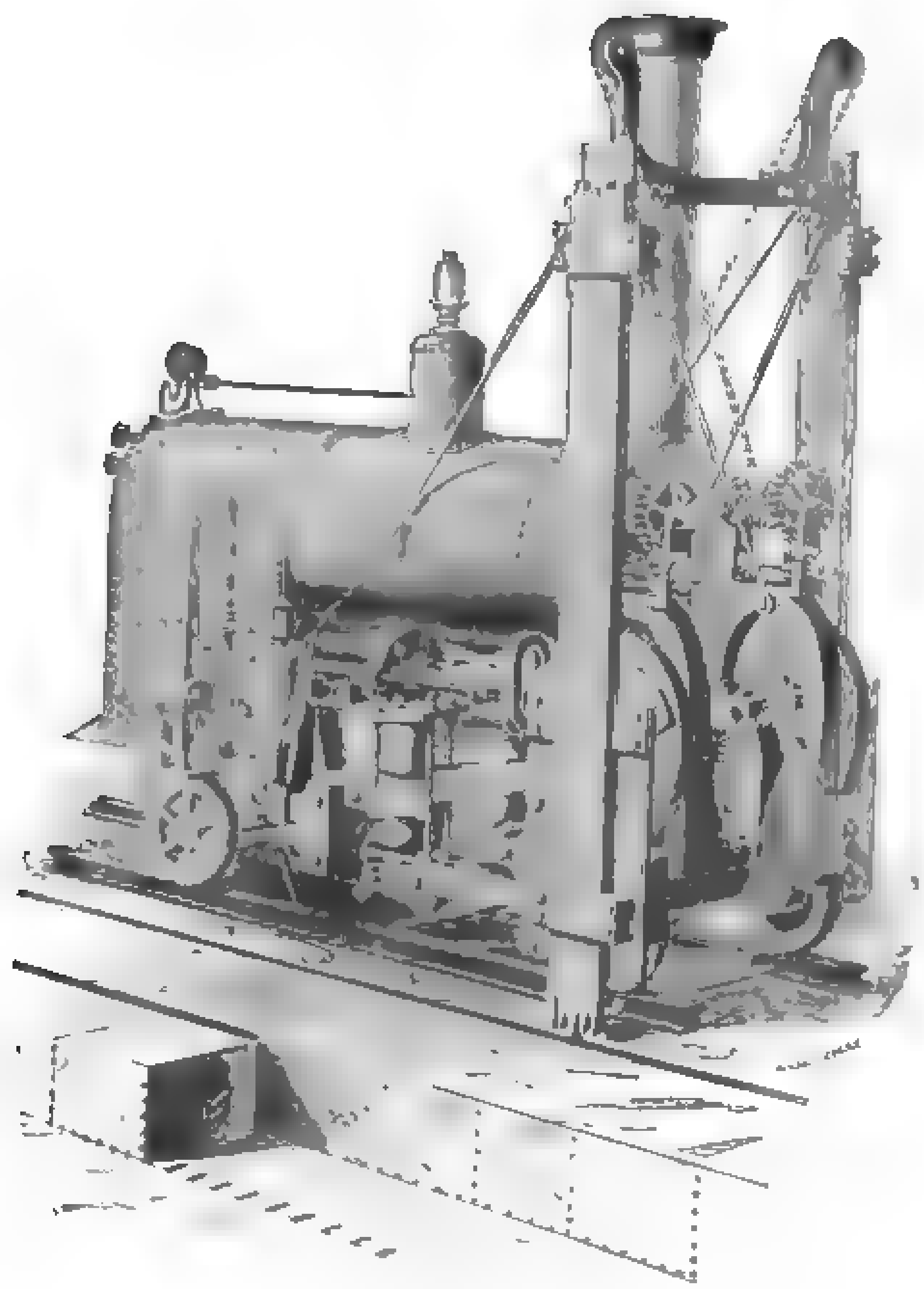
In the Wardwell machine there are five drills in the gang, three having their cutting edges transverse and two having them diagonal. The center one extends below the others, while the outer ones are the highest, thus forming a stepped arrangement from the central drill outward on both sides. The object of the diagonal cutting edges is to obtain an even bottom to the channel. When the machine is moving forward, the first three cutters, including the central one, do the cutting; when moving backward, the other two, with the center one, do the work. In the Ingersoll machine there is the same number of cutters in the gang, but they are all on the same level. The middle one is wedge-shaped and stands across the groove; the next one on each side is diagonal, and the outer ones are beveled only on the inside.

The Sullivan channeler, shown on Plate XXIII., is similar in its action to the Ingersoll and, like it, can be used with or without the boiler.

The bar channeler is now used extensively in many quarries, as it is cheaper, lighter, and adapted to more uses than the locomotive channelers. It differs from a rock drill mounted on a quarry bar (Plate XX.), only in using a gang of chisels instead of the drill bit. In action a hole the depth of the required channel is drilled at each end of the required channel, and the gang of chisels is made to go back and forth on the bar, cutting an open channel between the holes. It can be made to cut a channel at any angle, or will channel horizontally along the floor. It can be used for undercutting or gadding, and for drilling plug and feather holes.



SULLIVAN CHANNELER



WARDWELL CHANNELER, DOUBLE GANG

The ordinary rock drill when mounted on a quarry bar, as shown in Plate XX., is often used as a substitute for the channeler, by drilling a line of holes about three quarters of an inch apart and then breaking down the dividing walls by means of a broach.

Rate of cutting and cost of running channeling machines in different quarries.

Name of company.	Kind of stone.	Channeler.	Sq. ft. of channel in ten hours.*	Cost of running ten hours.
Sheldon Marble Co., W. Rutland, Vt	White marble	Wardwell ... Ingersoll .... Ingersoll bar. Sullivan.....	32 to 64.	$5 to $9
Vermont Marble Co., W. Rutland, Vt	White marble......	Wardwell ... Sullivan.....	37 to 63.	
Gross Bros., Lee, Mass	Marble	Wardwell	35 to 40.	$5
Hoosier Stone Co., Bedford, Ind...	Oölitic limestone...	Wardwell	90......	
Perry Bros., Ellettsville, Ind......	Oölitic limestone ...	Wardwell	100.....	$10
C. W. Babcock, Kasota, Minn..	Limestone.........	Wardwell	60......	$10
St. Lawrence Marble Co., Gouverneur, N. Y.....	Dolomite (marble)..	Diamond	45......	30c. per ft.
Tuckahoe Marble Co., Tuckahoe, N. Y.........	Dolomite (marble)..	Ingersoll	75......	$6 to $8
Snowflake Marble Co., Pleasantville, N. Y.....	Marble	Diamond........	50......	$10
Inyo Marble Co., Inyo, Cal.....	Marble	Sullivan.........	50......	

Rate of cutting.—With certain channelers, as with steam drills, we frequently hear of phenomenal rates of cutting, but it is the average work of the machines in the quarry which is of importance to quarrymen. Information has been obtained concerning their actual capacities, direct from the marble and limestone quarries where the machines are now in use. The rate of cutting varies greatly in different kinds of stone. The statements given in the accompanying list show that the rate per day varies from 32 to 100 square feet of channel face

*Counting one side of the channel.

(counting one side of the channel) and this is much less than that given in the manufacturers' circulars.

Cost of running a channeler.—The cost of running a channeler varies from $5 to $13.50 per day. The single gang machines require two men and the double gang machines three men, while for the double gang machines there is further cost in fuel, repairs, and wear of the machine.

Prof. H. M. Seeley says* that a good workman of the Vermont quarries would formerly cut by hand from five to ten feet of channel per day, at from 20c. to 30c. per foot.

The Sheldon Marble Company states that from three to five square feet of channel is a day's work for one man, and that he receives 55c. per square foot.

Sawing stone from the quarry.—There are two methods of sawing stone from the quarry, neither one of which has come into general use. The one used to some extent in this country is that in which the stone is cut by means of a portable quarry gang saw which resembles somewhat the gang saws in use in the mills. One size contains a gang of six saws, each sixteen feet long, twelve inches wide, and a quarter of an inch thick, composed of soft perforated steel. Water and sand or some substitute is used as with any other saw. It has been used in the limestone quarries of Iowa, in the oölitic limestone quarries of Indiana, and in the marble quarries of Georgia; and is said to work with a fair degree of success.

The other method of sawing stone from the quarry, used in Europe, is the invention of a Frenchman, M. Paulin Gay. It consists of an endless strand of three steel wires twisted together and running on pulleys. The cutting is done by sand and water as with the common blade saw, the spiral wire acting as a carrier. When properly arranged, the wire has three motions, the onward motion given it by the rotation of the pulleys, an advance motion as it cuts its way into the rock, supplied by a mechanical appliance attached to the pulleys, and a gyrating motion which is supplied partly by the shape of the pulley and partly by its friction on the stone. This last motion

*Marble Border of New England, p. 44.

serves to remove the mud, produced by the sawing, from the bottom of the cut. Its superiority over the blade saw is said to be its greater speed and its ability to cut hard stones, as grit and porphyry, which the blade saw will not cut; this is probably due to its continuous and more rapid motion. It is used in the quarry not only in cutting the boulders into shape, but also in cutting the stone from the bed, in which use it takes the place of the channeler. Its use in cutting stone from the quarry necessitates a sinking of wells or shafts to permit the apparatus carrying the wires to descend. This was formerly done by hand, but is now greatly facilitated by the use of the perforator, a machine similar in its work and practically the same as the diamond core drill. It consists of a sheet-iron tube, at the lower end of which is attached the cutter, which may be a diamond drill, a steel-toothed ring, or a wrought-iron one supplied with sand or metallic granules. This leaves a rock cylinder, which is knocked off and removed, leaving the opening for the descent of the wire-carrying pulley. This process is said to be both rapid and cheap.

One important objection to the wire saw is the wearing out of the wires and the consequent delay in replacing them; another is that it does not cut true; objections that might probably be overcome, as the many superior advantages of the method make it very desirable.*

This method is said to have been used successfully in the quarries of France and Belgium, but so far as known it has not been used successfully in this country. It was tried in the Vermont quarries but was soon abandoned.

DERRICKS.

The derrick is so important and so useful that no quarry can be equipped without one or more of them. The simplest form is what is called the "stiff leg," in which three beams are fastened together at one end with the other ends spread apart and resting upon the ground. This was probably the primitive form

*For illustration and further details of this process, see Stone, Vol. II., No. 5; or Scientific American Supplement, No. 520.

of the derrick, but it is not used in any of the large quarries nowadays.

The quarry derrick consists of a mast from 60 to 75 feet long supported by guys, and a boom 10 to 20 feet shorter, to which the lifting rope is attached. At its outer end the boom has a radial motion to and from the mast, while both mast and boom have a circular motion on the axis of the mast. Its construction gives it command of a circle of the quarry around the mast, varying in size with the size and strength of the derrick. These general principles are applicable to all derricks, and have been in use for a great many years. They differ much in minor details: they may be boom-lifting or not; geared with fast and slow speeds or not; have automatic safety attachment and brake or not; may be used with hand, horse, steam, or water-power; may use hempen or wire rope; may lift with a single rope or with a block and tackle; and may vary in the kind, number, and attachment of the guys.

Boom-lifting or non-boom-lifting derricks.—In the non-boom-lifting derrick the boom is adjusted by hand to the angle desired before the load is taken up; the boom-lifting derrick has an attachment by means of which the boom with its load may be raised or lowered with the same power which is used to lift the load. Quarrymen differ as to the relative advantages of these two forms, which no doubt are preferable or not according to the conditions governing each case. The superiority of the boom-lifting form lies in its greater reach, that of the second in its greater simplicity of construction and hoisting apparatus. Answers to inquiries sent to some of the leading limestone and marble quarrymen show that four use the non-boom-lifting, four the boom-lifting, and two use both forms; one of the latter says that the boom-lifting derrick is preferable. Prof. Saunders says* that the sandstone quarries and the New England granite quarries prefer the boom-lifting, while the Vermont marble quarries prefer the non-boom-lifting. Figure 9 shows a boom-lifting derrick; in the non-boom-lifting form the rope on the left passes to a hand winch on the back of the derrick as

*Stone, Indianapolis, August, 1890, p. 95.

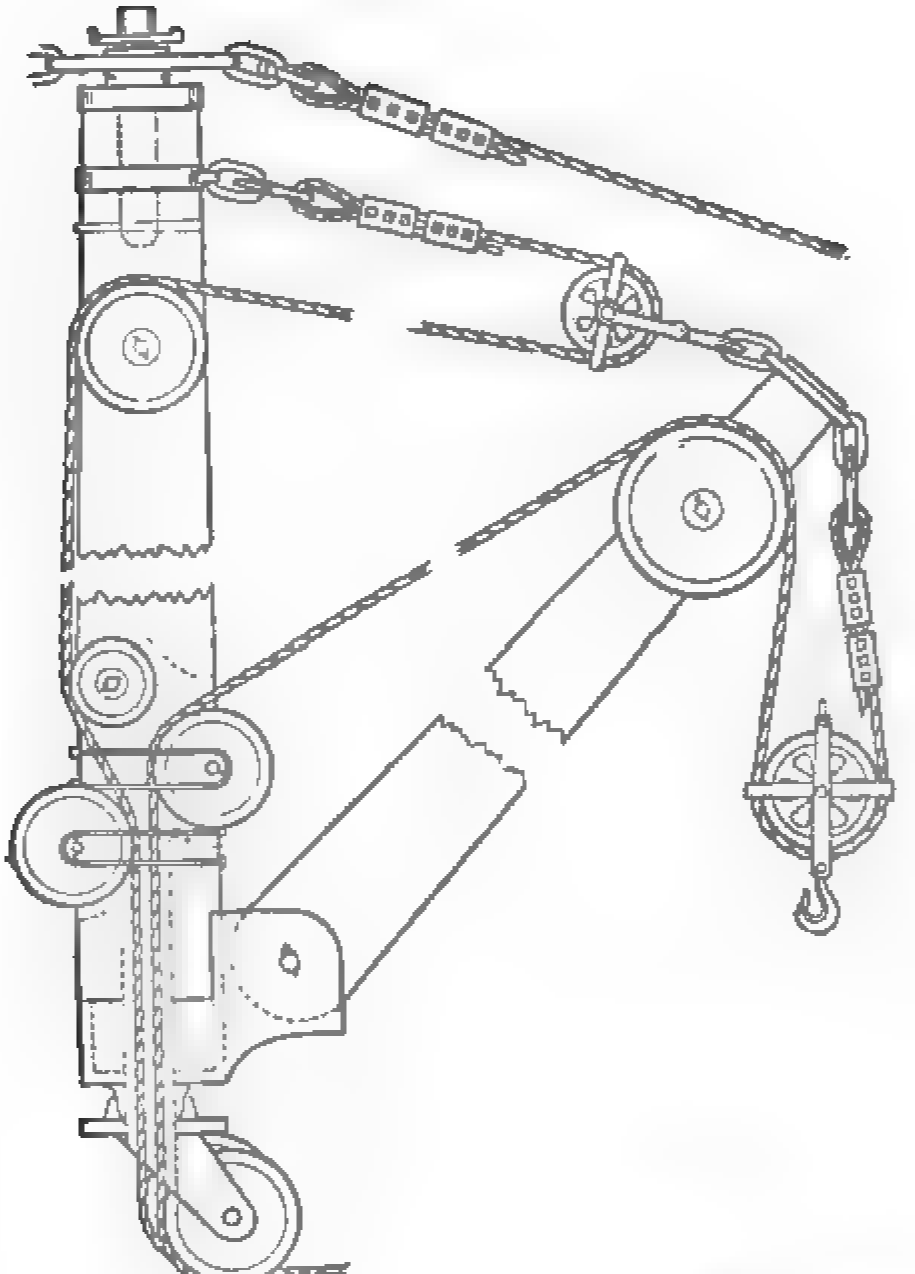


FIG. 9—*Gearing for boom-lifting derrick, operated with double drum.*

shown in figure 10 instead of passing to the power drum, as shown in the figure 9.

Power. — The power used with a derrick depends on the amount of work to be done and the size of the blocks to be handled. Where the blocks are not large and the use is not continuous, hand power is generally preferred. Figure 10 illustrates the gearing

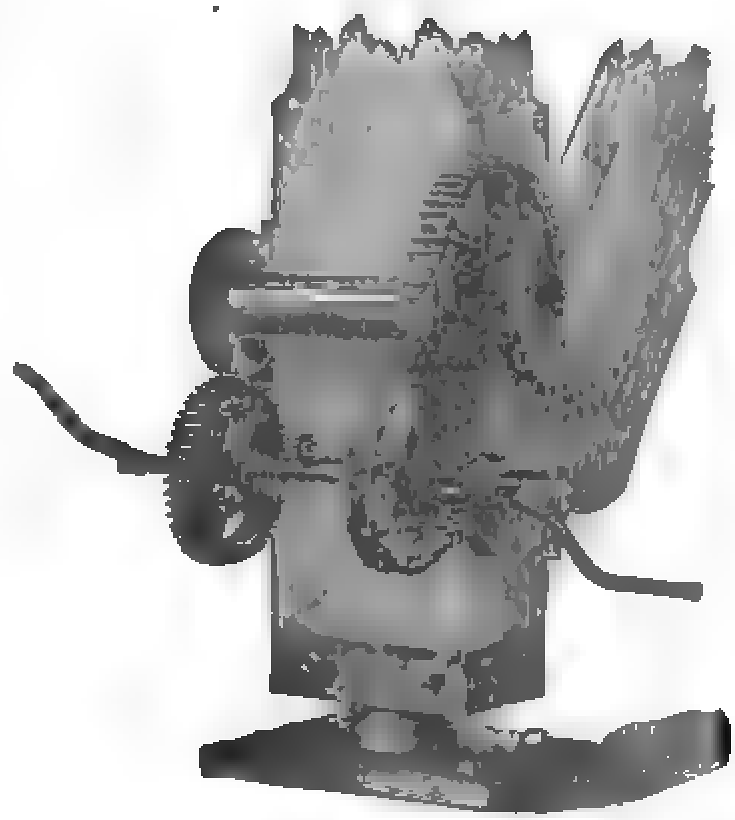


FIG. 10—*Hand power derrick.*

of such a derrick. Horse power attachment is used where much heavy lifting is to be done, while steam power is used where there is continued heavy lifting. Some quarrymen prefer to use a single line for lifting, while others prefer a block and tackle. The advantage of the first is simplicity; of the second greater lifting power for the force applied. Half of the number who responded to inquiries use the single line and half use the tackle block. Three fourths of those who use non-boom-lifting derricks use the single line, while three fourths of those who use the boom-lifting use the tackle.

Guys.—Derricks were formerly guyed with iron rods or links, but now wire rope is generally used. There should be at least eight guys, all well anchored to a good tree or a steel pin driven in rock, and the slack taken up at intervals for some months as the ropes stretch. Great care should be taken to see that the derrick is well guyed.

Care in erecting derricks.—The loss of life in the quarry from improperly constructed derricks is greater than that from any other cause. The danger sometimes comes from employing local, inexperienced foundrymen to get up the castings. The mistake is also sometimes made of employing poor timber in the mast and boom, and too frequently the derrick is poorly guyed. Persons opening a quarry should visit some of the leading quarry districts and copy after plants which have proved themselves satisfactory. The opinion has been expressed that there should be an official inspector of derricks in each state in which quarrying is done.

OPENING THE QUARRY.

Preliminary.—Much capital has been squandered in the quarry industry which might have been saved, had the promoters properly considered a number of points too frequently overlooked. The quality, quantity, and position of the stone must all be carefully considered. The commercial value of a quarry cannot be determined from a hand sample; it is necessary to consider the character of the bed as a whole, as an otherwise valuable stone may be worthless by a position which renders its quarrying too expensive.

The means of transportation is another serious question. A quarry that might be worked with profit on the bank of a navigable stream or on a railway, might be worthless several miles from either. Only the more expensive varieties of marble can profitably be transported by wagon for several miles.

Some stones are only adapted to a local trade, and it should be considered whether this will be large or small; a stone may be quarried profitably on a small scale, while a small demand for it will not permit the profitable employment of a large capital.*

Having selected the point for opening the quarry, the next step is to remove the overlying debris. In the northern regions this is commonly done in the winter preparatory to the work of the next season. The manner of removing it will depend on the quantity and nature of it and the skill of the operator.

Outfit.—In opening a quarry in a new region it is advisable not to make an expensive outlay for machinery until the quality of the stone is assured, as it is easy to enlarge the quarry equipment as the demand for the stone justifies it.

Prof. W. L. Saunders, in his notes on quarrying,† estimates that a first-class equipment for quarrying dimension stone, which includes derricks, boilers, pumps, channeling machines, rock drills, pipe, blacksmith's tools and fittings, costs about $8000; however, if the rock to be worked only promises well, but its quality or quantity is not assured, a good equipment, including channeling machine, rock drill, boiler pump, derrick, and hoisting apparatus can be obtained for $3500. It may not be advisable to purchase a channeling machine at first, and its omission from the list will greatly reduce the necessary outlay for the beginning of operations.

The prices of the different pieces of apparatus, as shown in

*In selecting the point for opening the quarry, it is advisable to consult an experienced quarryman, not one who is experienced simply in handling tools, but one who has had experience in selecting and quarrying similar stone elsewhere. He should have a fair knowledge of geology, or a geologist should be consulted. The core from a diamond drill is helpful in gaining a knowledge of the interior of the bed, but this must not be too implicitly relied upon.

†Stone, July, 1890.

the following list, will enable any one to figure out the cost of any outfit he may desire:

Cost of quarrying machinery.

Channeling machine, double		$2,500
Channeling machine, single	$1,800 to	2,200
Bar channeler		1,000
Steam drill, unmounted	145 to	425
Tripod	30 to	55
Quarry bar	175 to	250
Portable quarry gang saw	1,000 to	2,500
Derrick	200 to	1,000

The above quotations are the market prices for 1892, and many of them are subject to trade discounts. The cost of day labor, the price of hammers, drills, picks, etc., will vary with the locality.

The price of the derrick depends on so many conditions that definite figures can hardly be given, Prof. Saunders gives an itemized account of the erection of a large derrick in Manchester, Vermont, furnished by the president of the Taconic Marble Company, which amounts to $891.50; which amount includes all the material and labor in erecting it. The cost of all the fittings for a five-ton derrick similar to that shown in figure 9, exclusive of timber and rope, is $84, and for a similar one operated with a single drum is $76. A false economy in erecting a derrick is to be avoided.

METHOD OF WORKING A QUARRY.

The method of working a quarry depends on a great many conditions, such as the nature of the stone, the use for which it is desired, the natural location, the experience, skill, and ingenuity of the operator.

The channeling process is the one largely used in marble, limestone, and sandstone quarries, where the stone is massive or does not contain a sufficient number of natural division planes, either bedding or joint-planes. The common plan is to remove the debris overlying the stone to be quarried, from an area the size of the desired opening for the quarry. Having a comparatively level floor, the channeling machine is then

put to work and a series of channels of the required depth and distance apart are cut. The center block known as the key block, is then removed either by blasting or by breaking it loose from the bottom by means of wedges, inserting a lewis iron and lifting it out with the derrick. The remaining blocks are removed with the use of the rock drill or gadder. Another layer is then begun and removed in the same way. In this manner the quarry floor may be carried down to the bottom of the bed if desired. Plate IX. shows the appearance of a quarry, worked by this method, which has now reached a great depth. There are many minor details which necessarily vary with the locality.

The step or bench system.—Instead of removing an entire layer of the quarry floor at one time, there may be a ledge of varying width left at the back wall each time which will give it the appearance of a set of steps as shown on Plate XX. In this process the bar channeler (shown in the plate) is commonly used, on account of its being much easier to change from one ledge to another than the locomotive channelers and it does not require any track. Quarrying by this system is sometimes carried on without the use of a channeler, the blocks being released by wedging with plugs and feathers.

If the rock is cut by a sufficient number of natural free beds, the channeler is not needed except to work around the wall and to cut key blocks. The blocks can be removed by wedging, by which means, if the workmen are careful to work with the grain of the rock, quite regular blocks may be obtained.

In the Vermont marble quarries and in the oōlitic limestone quarries of southern Indiana, two of the most extensive quarry regions of the United States, the work is nearly all done with steam channelers and steam drills or gadders.

In the Tennessee quarries, while the channelers have been and are used in a few places, the position and nature of the stone is such that most of the work is done without channeling. In the summer of 1890 but one channeler was found at work in a number of the largest quarries in the vicinity of Knoxville. In the quarry at the junction of the French Broad

and Holston Rivers, four miles from Knoxville, the quarrying is all done by hand, the rough blocks being sawed into the desired shape at the mill. At Concord, ten miles from Knoxville, the work is in great part done by hand, one steam drill being used part of the time. At Caswell Station one channeler and two steam drills are used.

USE OF EXPLOSIVES IN QUARRYING.

Blasting powder was formerly used extensively in quarrying, but at the present day it has been almost entirely banished from the marble quarries of this country, and practically so from the large limestone quarries from which dimension stone is obtained. It is used largely in granite quarrying and also in a few of the smaller sandstone and limestone quarries, where the amount quarried will not justify the use of machinery.

Marble quarrying.—The two serious objections, which have caused the banishment of explosives from the marble quarry, are the waste of material and the injury done the rock by the jar of the blast, which opens up hidden seams or develops lines of weakness—defects rendered doubly serious by the fact that they frequently do not appear until after the stone has been placed in the structure. This is well illustrated by the Carrara marble, of which it has been said that most of the stone used by the Romans before the invention of gunpowder is firm and sound, while much that has been used since gunpowder quarrying began shows signs of decay. The injurious effects of the blast are often greatly increased in the Carrara quarries by another sometimes equally serious shock, produced by the large masses being blown out of the quarry on the mountain top and falling or rolling 400 or 500 feet down the mountain side.

Prof. H. M. Seeley says* that powder was used in a quarry at Sheffield, Mass., where blocks of marble 50 feet long were sometimes blasted out, and that the operation seemed to have been quite satisfactory.

The Knox Blasting Company has patented a system of

*Marble Border, p. 30.

blasting which they claim is adapted to quarrying all kinds of dimension stone. It is said to be used to a considerable extent in the sandstone quarries of Ohio and elsewhere, and to some extent in limestone quarries in Indiana and in the quarries of hard marble in Vermont.

In order to discover to what extent explosives are actually used in the marble quarries of the United States, the Survey made inquiries of the leading quarrymen in different parts of the country. The replies show that but two companies, the Inyo Marble Company of California, and the Vermont Marble Company of West Rutland, the latter being the largest marble-producing company in the world, use powder directly in quarry work proper, the latter employing it occasionally for pop blasts in raising layers. However, powder is used in other work than quarrying proper. Two thirds of the companies use it in stripping or clearing away the overlying worthless stone, and the Sheldon Marble Company of West Rutland, Vermont, uses powder for driving a tunnel in its quarries in the winter time.

Limestone quarrying.—Explosives are not used to any extent in the large limestone quarries where the stone is required for superstructures or in places where durability is an important feature. Where rough dimension stone is required for foundations, retaining walls, or similar uses, and the amount to be quarried at a certain place will not justify the purchase of machinery, powder is frequently used. The successful use of powder, however, for quarrying dimension stone requires much skill and experience.

In the use of powder for quarrying dimension stone the following suggestions, mainly derived from F. W. Sperr's article in the report of the Tenth Census, will be found helpful:

The limited number of directions in which a rock is liable to break is determined by the shape of the drill hole and the structure of the rock.

The first object, where it cannot be obained by the drill, is to a large extent governed by putting the charge in tin canisters of the required shape in large drill holes and tamping in with

sand, the effects of which are nearly the same as though the holes were drilled the shape of the canisters.

A break in a straight line is obtained when a horizontal cross-section of the charge is elliptical, or nearly so, in shape, the line of break being continuous with the longest diameter. This may be obtained by making the canister of two pieces of sheet tin, with the edges unsoldered and the ends made of paper or cloth, or without the canister by drilling two holes and chipping out the wall between them.

Two breaks may be made with planes crossing at right angles by making the canister a square prism.

Much depends on the nature of the explosive used; for dimension stone black powder is nearly always preferred to dynamite, as the former, slow acting like a powerful hydraulic press, tends to split the rock; but the latter sudden in its action, like a ponderous hammer, tends to shatter the rock.

Light charges covered with sand are preferable to heavy charges tamped in tight.

Light charges often repeated are less liable to shatter the rock than one heavy charge.

The successful quarryman will always take advantage of the bedding and joint-planes and the grain of the rock, as it is only the existence of such that render at all profitable the quarrying of certain rocks.

Broken stone.—Explosives are eminently adapted to the quarrying of broken stone for lime burning, railway ballast, macadam, rubble-work, etc., both powder and dynamite being used extensively for this purpose.

While the work preparatory to blasting may be done by hand, it is greatly facilitated by the use of a rock drill, either a steam, compressed air, or electric drill. The aim is to concentrate the explosive force at the point of greatest resistance, which is at the bottom of the hole, and cannot be done in a small drill hole. The hole should be cone-shaped, large at the bottom and small at the top. It being impossible to drill such a hole, this object is obtained by a process called squibbing, in which small quantites of a highly explosive compound,

as nitro-glycerine, are exploded in the hole, which burns and crumbles the surrounding rock, thus enlarging the hole at the bottom for the final blast. Another process, which is used in many places with certain kinds of stone, is called springing, in which the squibbing is done by larger blasts than in the former process, with a mild explosive as gunpowder or low grade dynamite, the object being to spring open the seams or cracks in the rock so as to admit the powder of the final blast, which is thus rendered more effective.

There is a great saving in dislodging the rock in large masses and then breaking it by block hole blasting instead of blasting it from the quarry in small pieces. The reason is found in the fact that the blast in the boulder or loose mass has a free face on every side on which to exert its force, while in the quarry it has but one or two. A blast which would shatter a hundred ton boulder to fragments would knock but a fractional part of that quantity from the face of the quarry.*

"At South Bethlehem, N. Y., extensive and economical broken stone quarrying is carried on, the usual process being to drill about 50 holes to a depth of nearly 30 feet each, extending along the face a distance of over 300 feet. Each hole is charged with about 40 pounds of dynamite, and with the use of the electric battery the range is exploded at once, throwing down about 25,000 tons of broken lime rock."†

JOINTS, RIFT, AND GRAIN AND THEIR UTILITY IN QUARRYING.

Joints are the natural division planes found in nearly all rocks; as a rule they are perpendicular to the bedding or stratification planes, and are commonly at somewhat even distances apart.

The joints, while commonly perpendicular to the bedding planes, are not always so, but vary in the angles at which they cut them; also in the sharpness of their definition, in the regularity of their perpendicular and horizontal courses, in their

*An illustrated article with interesting details of a large blast, costing $3,568.24, is given in the Transactions Am. Inst. of Mining Engineers, Vol. VII., p. 266, and Vol. X., p. 304.

†W. L. Saunders, Stone, December, 1889.

lateral persistence, in number, and in the directions of their intersections.

A complete and satisfactory explanation of the causes of joint structure has not yet been given, but in all probability, as Prof. Geikie says,* they have originated in different ways; or, in other words, what we commonly call joints may be the result of one of several distinct natural processes, among which he enumerates contraction, crystalline or magnetic forces, compression, and torsion.

In many limestones the joints are invisible until opened by the percolation of surface waters, the action of frost, or some other agency, in which places they are liable to be very annoying to the inexperienced quarryman.

It will thus be seen that the value of a rock may be very seriously affected by its joint structure, an excessive number of joints sometimes rendering an otherwise valuable stone useless. A great irregularity in the joint-plane may cause a great waste of labor and material, and an absence of a limited number of joints will increase the cost of quarrying the stone. By these joints nature has already performed a large part of the work of quarrying the stone, as where they are conveniently distributed the quarryman has but to wedge loose and lift out the block between the intersecting planes, sometimes only the latter operation being necessary. But while the joints so greatly facilitate the work of the quarryman, they necessarily limit the size of the blocks which can be obtained.

The effect of the joints is often strongly marked on the topographic features of the region, as the angular ledges and perpendicular cliffs so prominent in many limestone regions are due to weathering influences acting along these joint-planes. This feature is prominent in many of the White River bluffs in Arkansas.

The rift of a rock is the direction parallel to the bedding or foliation, along which it splits with the greatest ease. This is utilized by the quarryman in the dolomite ("cotton rock")

*Geikie, Text-Book of Geology, p. 490.

quarries along the Eureka Springs Railway, where the stone is frequently split into flag and curbstone.

The grain is always in a direction at right angles to the rift, and signifies the way the stone dresses the most readily across the bedding. Wherever possible the stone is worked either with the grain or the rift.

METHODS TO BE USED IN QUARRYING THE ARKANSAS MARBLES AND LIMESTONES.

Different methods will be required in the different beds and even in the same bed under different conditions.

Dolomites ("cotton rock").—Along the Eureka Springs Railway, where large quantities of dolomite are quarried, the stone occurs in regular and comparatively thin layers. The quarrying is all done by hand, by wedging, the stratification planes being so regular and numerous that channeling machines are unnecessary. A steam drill could be used economically in place of hand power in putting in the holes for the plugs and feathers. In many other places these dolomites occur in heavier layers, sometimes three or four feet thick, but in no place so far as known to the Survey are the beds massive enough to render channeling necessary or economical. A steam drill is all the machinery needed; and the bench system will in most places be the most desirable manner of working the quarry. Where the stone occurs in heavy layers, it would be economical to have a sawmill at or near the quarry to reduce the stone to the proper dimension.

The Izard limestone.—The "plucky" nature of the Izard limestone precludes its use in buildings with other than a rock face. Owing to the numerous joint-planes it can be worked by hand economically, in many places the only machinery needed being a rock drill. Owing to its desirability for that purpose, much of this stone may be quarried for lime burning, and it can be done most economically by use of the steam drill and dynamite or blasting powder.

The St. Clair marble.—In many places the St. Clair marble is massive, with few or no stratification planes. The bedding

planes which show on the weathered slopes are frequently due to weathering, as on cliffs in the immediate vicinity where the rock has not been exposed so long, it is frequently the case that no bedding planes are visible. The manner of working the quarry will depend on whether it is opened on the level, on the sloping hillside, or on the face of the cliff. If opened on the level, it must be worked in the open pit as in many of the Georgia and some of the Vermont quarries (see Plate IX.). If opened on the sloping hillside, it can be worked either by the step system or by open cut with perpendicular back wall. By any of the methods channelers and percussive drills will be needed to carry on the work economically. To open the quarry in the face of a perpendicular cliff is attended with difficulty, but the great saving in the expense of removing the overlying and waste material will compensate for a heavier expense in carrying on the work. Channeling machines are now made to channel on a perpendicular face, which method is illustrated in figure 11.

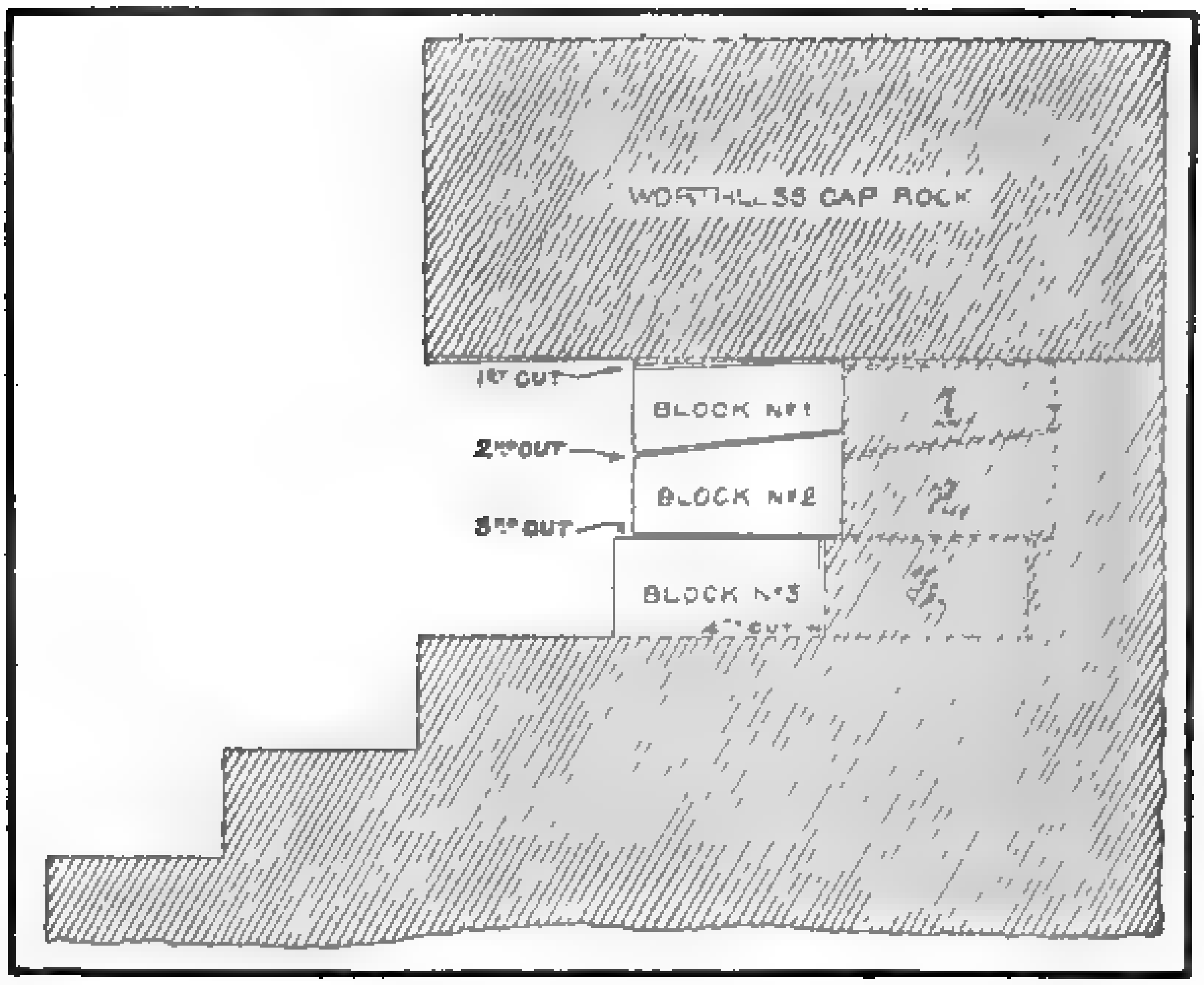


FIG. 11.—*Channeling on the side hill.*

If channeling in this way can be done successfully the cost of opening a quarry on the face of one of the numerous bluffs would be slight, as sound valuable marble would be found almost from the start.

A promising opening for a quarry would be on the point of the hill between two ravines at their confluence. At such a place there is generally a large exposure of the marble, and the hills often being quite steep, the overlying material can be disposed of at little expense. It would not be difficult in many places to obtain three free faces which would certainly add much to the economy of quarrying. A quarry so situated would be peculiarly fitted for the use of the spiral wire saw described on page 368. By running the wire across one of the narrow ridges the rock might be sliced off in slabs of any desired thickness or size, and without the expense of making the openings or wells for the descent of the pulleys carrying the wires. In many places also there is water enough to furnish sufficient power to run it. But whatever process is used, a quarry so situated could be worked more economically than one otherwise located, and owing to the great erosion in the area, numerous exposures of this kind occur.

The St. Joe marble.—The St. Joe marble in many places occurs in a position similar to that of the St. Clair, and can be similarly quarried. Yet in many places, probably in most places, the St. Joe marble has a sufficient number of bedding planes to be quarried without the use of a channeling machine. By means of plugs and feathers the blocks can be split from the ledge. As the St. Joe marble is much harder than the St. Clair it would be more expensive to channel.

The gray limestone and marble in the Boone chert occur in regular layers, the separate layers rarely if ever exceeding three or four feet in thickness, so that they can be quarried by drilling and wedging.

CHAPTER XXVIII.

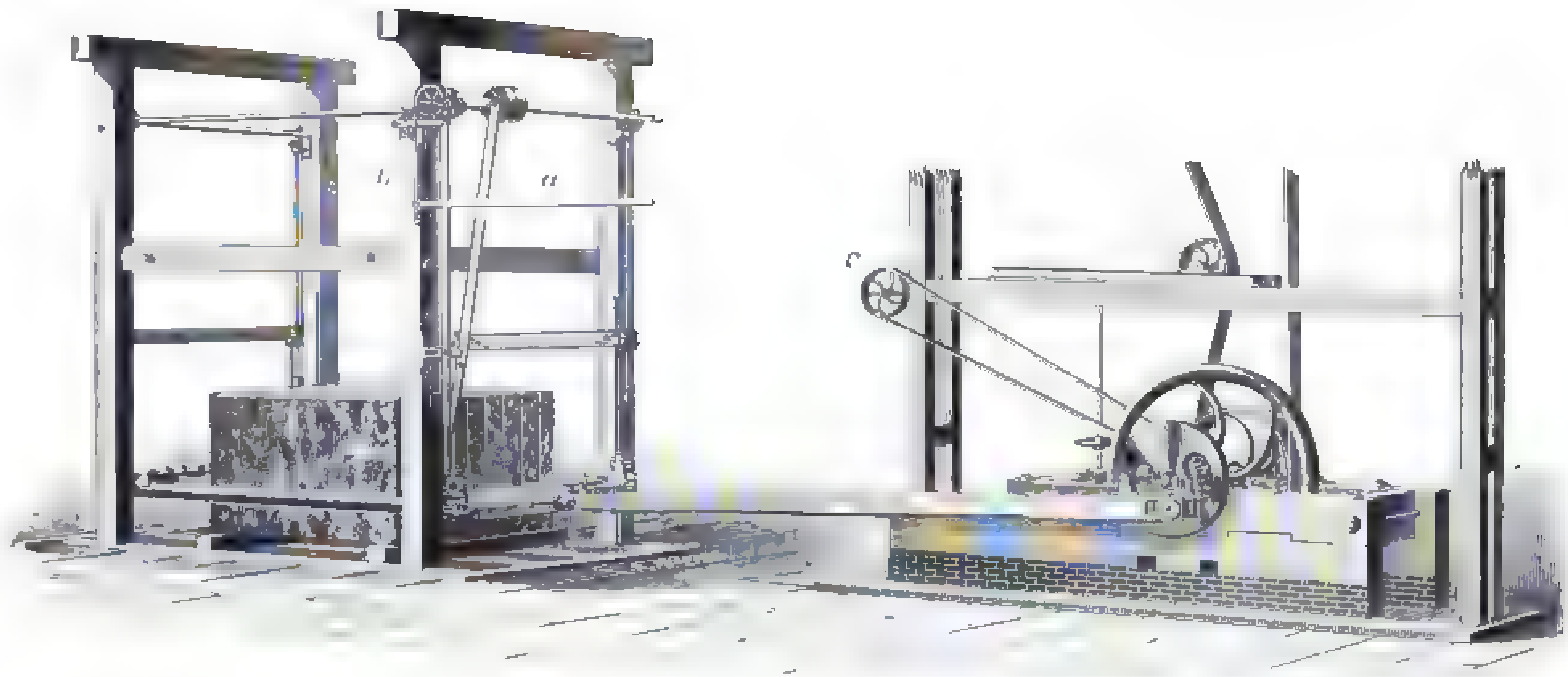
Cutting, Dressing, and Polishing Marble.

MACHINES.

By the use of channelers, steam drills, and portable saws, dimension stone for some purposes is cut to the desired size and shape in the quarry, but nearly all the marble and most of the limestone for dimension stone are cut into the desired shape after leaving the quarry. The aim in quarrying is to obtain the blocks in a form as regular as is consistent with economy. While some of the finishing work can be done in the quarrying operation, much of it cannot be so done, while most of it can be done more economically in the marble mill or yard, by especially prepared machinery or by hand.

Nearly every marble producing company and many limestone companies now have one or more mills to do the finishing work, located either at the quarry or centrally located where it can receive the product from several quarries; in these mills the stone receives the desired size, shape, and finish.

Saws.—Most of the sizing is done by sawing. The gang-saw is especially adapted to the economical sizing of marble and limestone, although it is used on other rocks. It consists of a number of toothless blades of soft iron set in a frame in a horizontal position, and capable of a to-and-fro motion. It is connected by a single or double pitman with a steam engine or some other power, which moves the frame of saws back and forth across the stone to be sawed (see Plate XXIV.). The cutting is done by a combination of the iron blades with sand (or some substitute for it), and water; the cutting is done mostly by the sand, the water keeping the saw cool, softening the rock, and aiding to carry the sand under the saw and to remove the marble dust. The saw may be of any length desired, but they are commonly from six to eight feet long; possibly



MERRIMAN GANG SAW.

the largest gang-saw in the world is one in a Vermont mill, which will saw a block eighteen feet six inches long by ten feet square. The blades are commonly about an eighth of an inch in thickness and one gang may contain any number desired, sometimes having as many as sixty saws to a gang. The frame carrying the saws is fed down automatically as the saws cut into the stone.

Numerous devices are in use to feed the sand and water to the saws. It is claimed for these devices that they are a great saving of both sand and labor over the old process, in which the sand was shoveled on the stone by the workman and washed under the saw by the water which trickles from tubes overhanging the block. By the hand process one man attends to two gangs, while it is claimed with the patent saw-feed one man can look after twelve gangs.

The rate of cutting varies with the quality of the stone and no doubt with the arrangement of the saws. The rates given in the manufacturers' circulars are as follows for a day of ten hours: in granite from seven and a half to twelve inches; in marble from nine to twenty inches; in limestone from ten to forty inches, the figures referring to the depth of the cut without reference to the size of the blocks and the number of saws. At Carthage, Missouri, in the gray marble from the Boone chert formation, the rate of cutting is from ten to fifteen inches per ten hours.

Some idea of the great quantity of marble cut in this way may be gained from the fact that one firm in Vermont has 194 gangs of saws, some of them carrying as many as 60 saws each, in constant operation, and they were building 40 additional gangs in 1891.

Most of the sawing is done with steam-power, but where water-power is available it is much cheaper. It is stated by Prof. Seeley* that the cost of sawing marble by water-power at West Stockbridge, Mass., is five cents a foot, and by steam-power twenty-eight cents a foot. This is possibly an extreme case, but it suggests the value of the excellent water-power

*Marble Border, p. 32.

facilities in North Arkansas, where there are numerous waterfalls at or near the base of the marble bed. At several places this power is now utilized in part for grist-mills, sawmills, and cotton gins, and in the working of the marble beds it will no doubt be found of great advantage.

Many other contrivances for sawing stone have been used in different places. Circular saws with steel teeth, and others with diamond or black carbon teeth have been used.*

Planing machines.—Prof. Seeley says,† that Charles Boynton in 1836 invented and used for years a machine for planing marble, by which not only plain surfaces could be cut so smooth that, for ordinary purposes, no further polishing was required, but also straight mouldings could be cut with great facility and exactness.

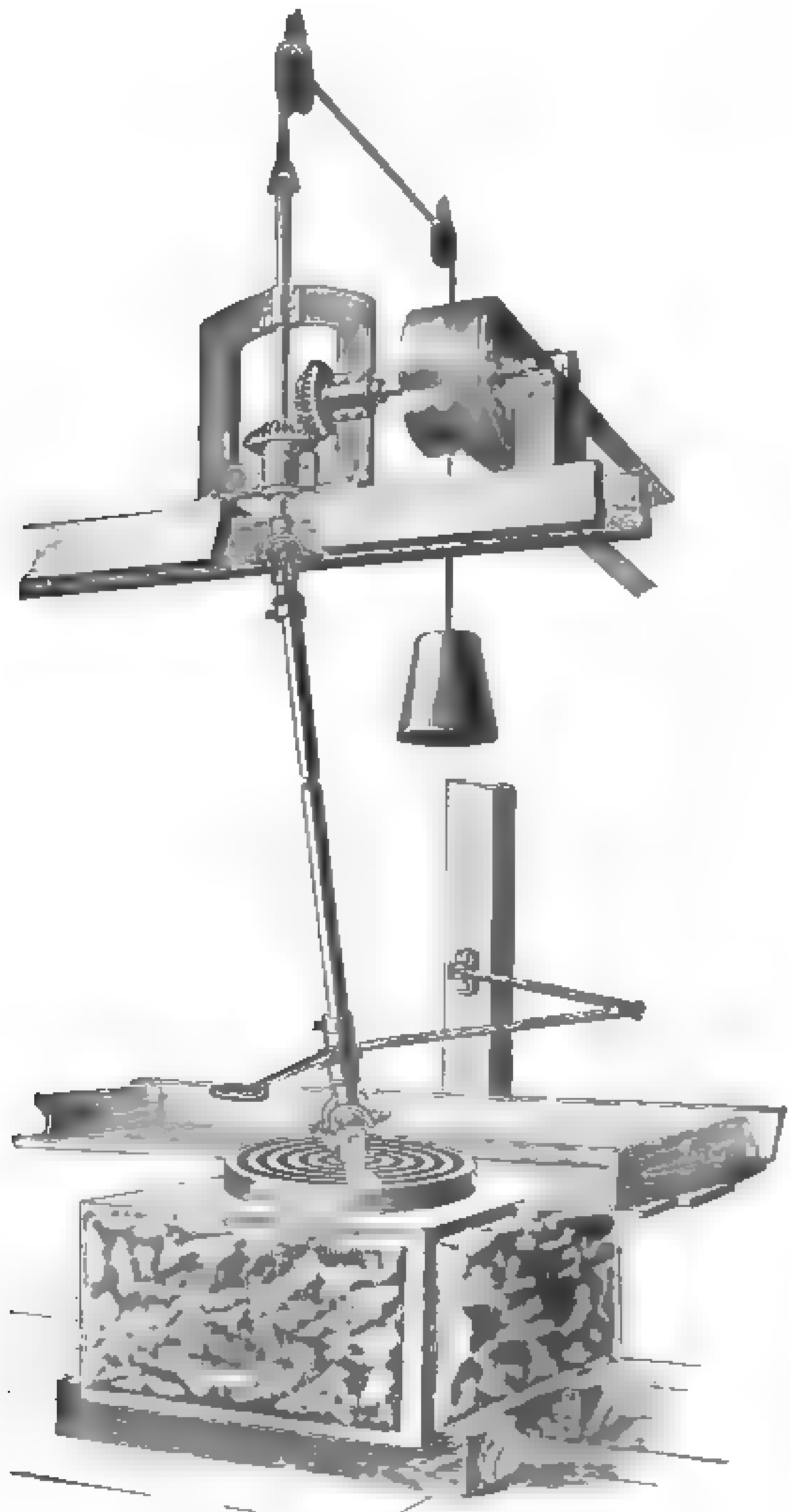
There are several such machines on the market now, which are used in dressing marble and limestone. Inquiry was made of a number of the oōlitic limestone quarrymen of southern Indiana as to the practical value of these machines. All of them reported that the work done by the planing machines was better and cheaper than hand work, and that the difference in cost varies with the class of work, but on an average it costs only about one half as much as hand work. They are used on sawed, channeled, or rough stone for plane surface or moulding, producing a face equal to a fine sand-rubbed finish. The planing machines are made of different sizes, one of the largest planing a stone twelve feet by eight feet by three feet, dressing the top and the sides at once. Such a machine is shown on Plate XXV., which is the kind used in the Vermont marble quarries and in the Indiana limestone quarries.

Brunton and Trier, London, make a machine for dressing stone, which is used extensively in Europe, and which differs from the machine in use in this country. Stone working machinery was introduced in France in 1842.‡

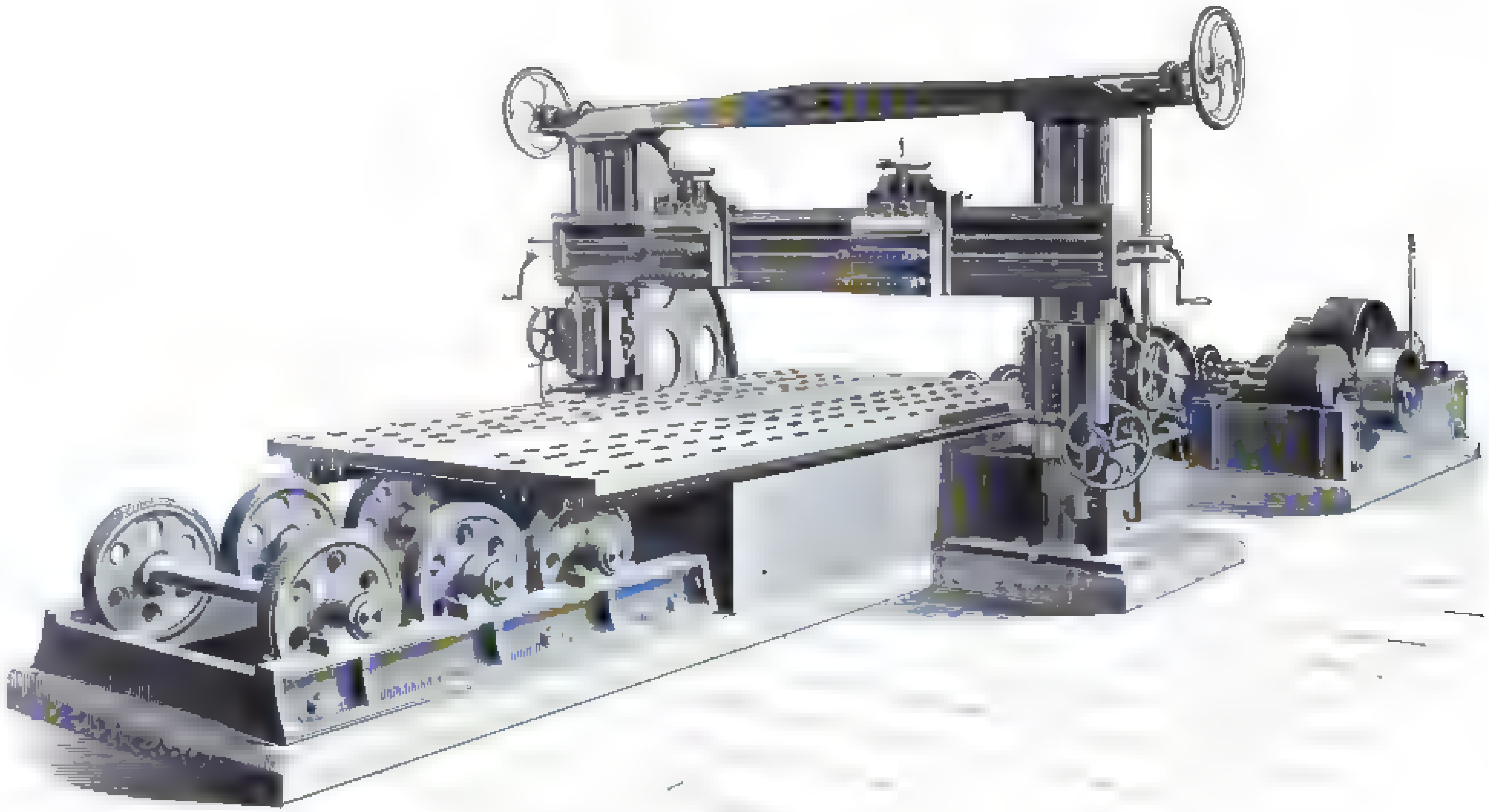
*Henry Conradi, before the Society of Engineers, London, several years ago, stated that circular saws for stone-cutting were being introduced with much success into England, resulting in economy of time and power. Scientific American Supplement, No. 54.

†Marble Border, p. 32.

‡Rapports sur L'Exposition Universelle en 1878, Les Marbres par Adolphe Violet, p. 73.



CONCORD POLISHING MACHINE.



STONE PLANER FOR PLANING MARBLE AND LIMESTONE

Lathes. Lathes of all sorts and sizes are in use in the marble mill for turning out columns and vases, and are essentially the same as those used for wood and iron. After the stone has been turned to the size and shape desired, a polisher is substituted for the chisel, and the column or vase is polished before it is removed from the lathe. Columns twenty feet and more in length and more than three feet in diameter may be fashioned in this way much better and cheaper than by hand.

Grinding and polishing machines.—Different contrivances are in use for rubbing the stone smooth preparatory to polishing it, the most common of these consisting of a heavy cast-iron plate made to revolve in a horizontal plane. The plate is revolved by a perpendicular shaft through the center and geared to the power either above or below the bed. These plates are of various sizes, generally ten to twelve feet in diameter, and are turned by means of steam or water-power. On this revolving bed the marble to be ground is placed, the light slabs weighted down and the heavy blocks supported by tongs or grapnel from overhead, while sand is shoveled on by a workman and water supplied from a pipe. A great many pieces of marble may be ground on one bed at the same time and at a small expense as compared with grinding by hand. The polishing of the pieces after they leave the rubbing bed may be done by hand or by machinery.

Machines, in which the wheel is placed on top of the block instead of the block being placed on the wheel, are in use for grinding and polishing. Plate XXVI. shows the Concord polishing machine, manufactured in Penacook, N. H., which is used extensively in the United States for both grinding and polishing; in the first process, some abrasive as sand, emery, or chilled shot is used; in the second the wheel is replaced by a felt rubber.

The grinding and polishing of panels and large slabs are done by machinery in the large mills, while the polishing of the smaller pieces and intricate designs is mostly done by hand.

The sand blast as a means of cutting stone was first used in

West Rutland, Vermont, in 1875–76,* where it was employed in lettering tombstones for the National Cemeteries. In this process letters and figures of chilled iron were placed on the space to be occupied by the inscription; the parts to remain uncut were protected by an iron shield; the sand blast was then turned on, and it rapidly cut away the unprotected part, leaving the letters standing out in bold relief. In this way the name, company, regiment, and rank of a soldier could be put on a stone in less than five minutes' time. By this means 254,000 lettered headstones, three feet by ten inches by four inches, were put up at an expense to the government of $864,000.

The machines now in use have a sand hopper connected by means of a flexible tube with a pipe, through which a jet of steam is driven. The pressure of the steam causes a vacuum, and the sand is drawn into the blast, whence it is thrown against the surface to be cut, the portion to be left in relief being protected by an iron shield.†

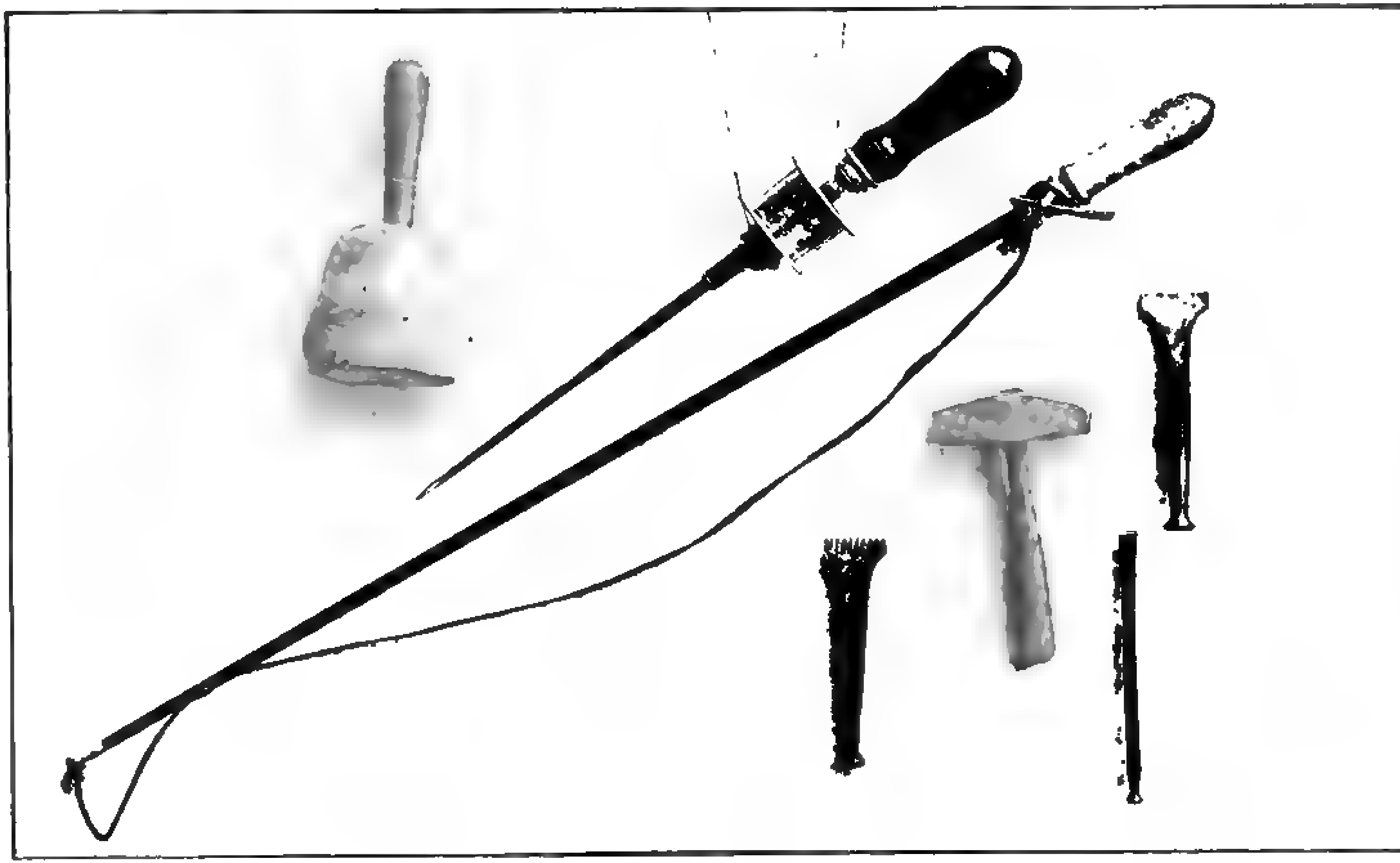
TOOLS.

Mallets.—Mallets should be made of the best quality of second growth shell-bark hickory, seasoned without cracking. Three sizes are needed, one from two to three pounds, one from three to five pounds, and the other from five to seven pounds in weight. The first is used for carving, the second for pointing, and the third for droving.

Hammers.—Several kinds of hammers are needed, one of the most useful being a hand hammer from three to five and a half pounds in weight. The striking hammer or sledge used for striking the drills in hand-drilling varies from ten to twenty-five pounds in weight. The pean hammer or stone ax has sometimes one, sometimes two cutting edges, which, when toothed, give it the name of a toothed ax. The bush hammer, called by some a patent ax, consists of a number of steel blades, four, five, six, eight, ten, or twelve in number, bolted together so as to form a single piece, and having sharply

*H. M. Seeley, Marble Border, p. 39.

†A. Lee, Marble and Marble Workers, p. 141.



MARBLE-CUTTERS' TOOLS.

grooved striking faces. Another variety, called the diamond hammer in Europe,* and patent hammer by some, is constructed of a single piece, still retaining the grooved face.

The crandall consists of a number of double-headed steel points passed through a slit in an iron bar and keyed fast, thus forming a toothed hammer.

The marteline hammer is a sharp pointed pean hammer.

Pick.—The stone pick is somewhat shorter and stouter than the ordinary pickax, and is used for rough dressing or channeling.

Drills.—The drill shown in Plate XXVII. is used by marble workers in carving. The common rock drills are described on p. 359.

Wedges.—The plugs and feathers are commonly two or three inches in length; gadding irons, or those used in wedging large blocks from the quarry, are much longer. The feathers are of soft iron, and the wedges are commonly made of steel.

Saws.—The grub-saw consists of a thin blade of soft iron, with a stout wooden back, which makes it convenient to handle and prevents the blade, which is made of soft iron and sometimes notched, from bending. These saws are of various sizes, up to four feet in length. Sand or some substitute is used with it to do the cutting. A skilled workman makes a groove in the rock with one of these saws, and then by a quick blow divides the block along this groove. Other varieties of hand-saws are used, some long heavy ones being worked by two men.

Chisels.—A great many different kinds of chisels and tools allied to the chisels, such as the tooth chisel, bush chisel, splitting chisel, drafting chisel, and pitching chisel, droves, points, and special carving and moulding tools, are needed by the stone-cutter, and should all be made of finely tempered steel of the best quality. The temper and the shape of the bit vary with the kind of stone to be cut.

Rifflers and files are used in cutting delicate carving and moulding.

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*School of Mines Quarterly, June, 1883, p. 367.

Other tools.—A well equipped marble workshop will need many tools and appliances which are common to almost any workshop, such as benches, vices, compasses, squares, rules, levels, etc. Plate XXVII. shows the most important tools of a marble-cutter's kit.

GRINDING AND POLISHING MATERIALS.

Sand, which in common parlance refers to granular particles of more or less impure silica, is one of the most common abrasives in use. It is commonly obtained as loose sand, but in some places it is obtained by crushing the sand rock. It occurs in varying degrees of fineness and purity, the best for most uses being a comparatively pure, clean, white, medium fine-grained variety.

Grit is a sandstone used for grinding; some of the varieties in the market are known as Berea grit, red grit, Nova Scotia blue grit, and common coarse grit.

Novaculite (from *novacula*, a razor) is an exceedingly fine-grained cryptocrystalline, siliceous rock, used in the solid form for putting a fine edge on tools, a smooth surface on stone, or any other fine grinding, and is also used in the form of a powder for grinding and polishing. The chief and almost the only source of novaculite is in the region west and southwest from Little Rock, Arkansas. Rocks suitable for whetstones are obtained in Indiana and a few other places, but they are not true novaculites.*

Emery, one of the most important and valuable of abradants, is an impure form of corundum, or a mixture of corundum and magnetite, yet both corundum and emery are commonly known in the market as emery. It is used in the form of a loose powder, or as emery cloth, paper, cakes, sticks, or wheels. It is much harder than sand, and with it rock can be ground down more rapidly. It is in the market in different grades of fineness for different uses—the coarser for rapid cutting on rough surfaces, the finer for reducing to a smoother finish. The Min-

*For full particulars, see Vol. III. of the Annual Report of the Geological Survey of Arkansas for 1890.

eral Resources of the United States for 1888 states that the only places in this country which produced emery for the markets in that year were Laurel Creek, Georgia, and Cullasaja, North Carolina, the total product being 589 tons, valued at $91,620. The imports for the same year amounted to $118,246.

Shot, composed of globules of chilled iron, is used now in many places instead of sand for sawing and grinding stone. It is claimed by those who use this shot that it cuts more rapidly than sand, emery, or corundum, and is said to be more economical, owing to the fact that it can be used many times. It requires greater weight or force on top of it than sand, as the grinding is done by the smashing or crumbling of the little particles of stone under the separate grains. In sawing it is claimed by the manufacturers that the shot not only cuts more rapidly, but that the wear on the saw blades is not so great, and that it is much easier to keep the cut straight.

Crushed steel as an abradant is rapidly growing in favor. It is made by quenching very highly carbonized steel in cold water, while the steel is at a high temperature, which renders it very hard and brittle. It is said to be much more enduring than natural abradants and to cut much more rapidly. An objection offered to both the crushed steel and the chilled shot for use on white marble for either sawing or grinding, is that it stains the marble with iron rust. The manufacturers claim, however, that lime water will prevent rusting.

Scotch hone, known as snake stone, or water-of-Ayr stone, is a soft, fine-grained, siliceous rock used for polishing.

Rottenstone is defined by Prof. Geikie as a siliceous limestone from which all the lime has been removed, leaving a siliceous skeleton of the rock. The silica is finely divided and is used, where a good quantity is attainable, for polishing. The Eleventh Census (Bulletin No. 78) reports a siliceous limestone quarried in Kentucky that is used for polishing marble.

Tripoli, used as a polishing powder, is an infusorial earth composed of the siliceous shells of microscopic infusoria, and is closely allied in appearance to rottenstone. While it is found in several localities in this country, the Mineral Re-

sources for 1888 says, that the only producing locality is that near Dunkirk, Maryland. In southwestern Missouri is a bed of amorphous silica which very closely resembles tripoli in appearance, and which is marketed in considerable quantities as a polishing powder. Analysis shows it to be over 98 per cent. silica. A deposit of similar nature occurs in Lee's Mountain, Marion county, Arkansas, a microscopic examination of which shows numerous minute crystals but no trace of organic remains. Mr. L. S. Griswold, of the Survey, states that a somewhat similar but slightly coarser siliceous powder occurs in Montgomery county, Arkansas.*

Bristol or Bath brick is made of a siliceous mud, taken from the bottom of the river Severn. It is compressed and baked, thus forming a coarse polishing substance.

Pumice stone is a volcanic product, a very light, porous lava, rendered porous and vesicular by escaping steam and other gases. It is used in marble-working to give the stone a smooth finish, finer than that produced by the sand or emery, preparatory to the final gloss or polish. While the world's supply of this product is practically furnished by the Lipari Islands, yet it is mined near Lake Merced in California, from which locality about seventy tons were obtained in 1885;† it is reported that a company has recently commenced operations on the Teneriffe Peak.

Chalk is used for polishing metal work but is rarely used on stone.

Colcothar, Crocus, Crocus of Mars, Venetian red, or rouge, is a finely divided oxide of iron produced by heating ferrous sulphate, or copperas. The term Crocus is sometimes limited to the product obtained from the bottom of the crucible, and rouge to that obtained from the top. It has an extensive use as a polishing powder, and is said to be used with good effect in polishing black marble.

Zinc, both in the solid form and as zinc dust, is used for polishing.

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*Vol. III. of the Annual Report for 1890.

†Mineral Resources of the United States, 1885, p. 433.

Putty powder is the oxide of tin or mixtures of oxides of tin and lead, and is the substance used to give the final gloss to polished marble. It is made by dissolving metallic tin in nitro-muriatic acid, and precipitating with liquid ammonia. The oxide is then washed, collected in a cloth filter, and squeezed dry between linen, when it is subjected to pressure, placed in a crucible heated to a white heat, and afterwards ground up for use. It is adulterated with lead, and thus four or five different qualities are made.*

Oxalic acid is sometimes used in place of putty powder for the final polish of marble, but as it injures the stone it should not be used.

Various so-called lightning polishers are made of oxalic acid mixed with other ingredients which bring a polish with less work but are injurious to the stone. Alum is sometimes used for the same purpose, but is equally injurious and should not be used.

Fullers' earth, a clay containing fine siliceous particles, is sometimes used as a polishing material.

Rabat is a potter's clay, which has failed in baking, but which marble workers sometimes use in polishing marble.

Diamond dust and graphite are sometimes used for grinding and polishing, but are rarely used on marble.

METHODS OF WORKING STONE BY HAND.

Machinery now does much of the work of cutting and dressing stone which was formerly done by hand, but there is a great deal of work that cannot be done satisfactorily by machinery, and often the small amount of work at a given locality will not justify the erection of machinery. But inasmuch as a much larger amount of stone is now used for architectural purposes than formerly, the demand for stone-cutters is increasing rather than diminishing.

Splitting.—While large blocks of marble and limestone are generally sawed into smaller blocks, it is sometimes found to be more economical to split them by hand. At the present

*Stone, October, 1890, quoted from the Stonemason.

time the common method, when the work is done by hand, is to split it by wedges, called plugs and feathers from their form. A series of holes about three fourths of an inch in diameter and seven or eight inches deep is drilled along the desired break, into each of which two thin hemi-cylindrical or half round pieces of iron "feathers" are placed, and between them a steel wedge or plug. The workman, hammer in hand, moves along this line and taps each plug in turn until the necessary strain is produced and the rock falls asunder. The skilled workman judges of the relative strain on each wedge by the sound it gives under the hammer, and by learning to take proper advantage of the rift and grain of the rock, the stone is rapidly brought into regular forms by this method.

Cutting.—Some of the many different kinds of finish given to stone designed for architectural uses are shown on Plate XXVIII.* The following description of the method of doing the work is given by Mr. Marcus Murray of New York, a practical stone-cutter of many years experience.†

No. 1. *Fretwork.*—This is made with straight grooves of many turnings, but in all cases at right angles to each other and with width of grooves equal to width of spaces. This work is accomplished with a carving splitter, three sixteenths of an inch wide.

No. 2. *Grecian Doric fluting.*—The tools used are tooth chisels and plain chisels one fourth to one half an inch wide.

No. 3. *Corinthian and Ionic fluting*, with beads worked in. The tools used are tooth chisels and plain chisels, one fourth to one half an inch wide.

No. 4. *Frosted work*, with random pencilling. The holes are sunk with a carving splitter one fourth of an inch wide. The ridges are rounded off by a tooth chisel three eighths of an inch wide.

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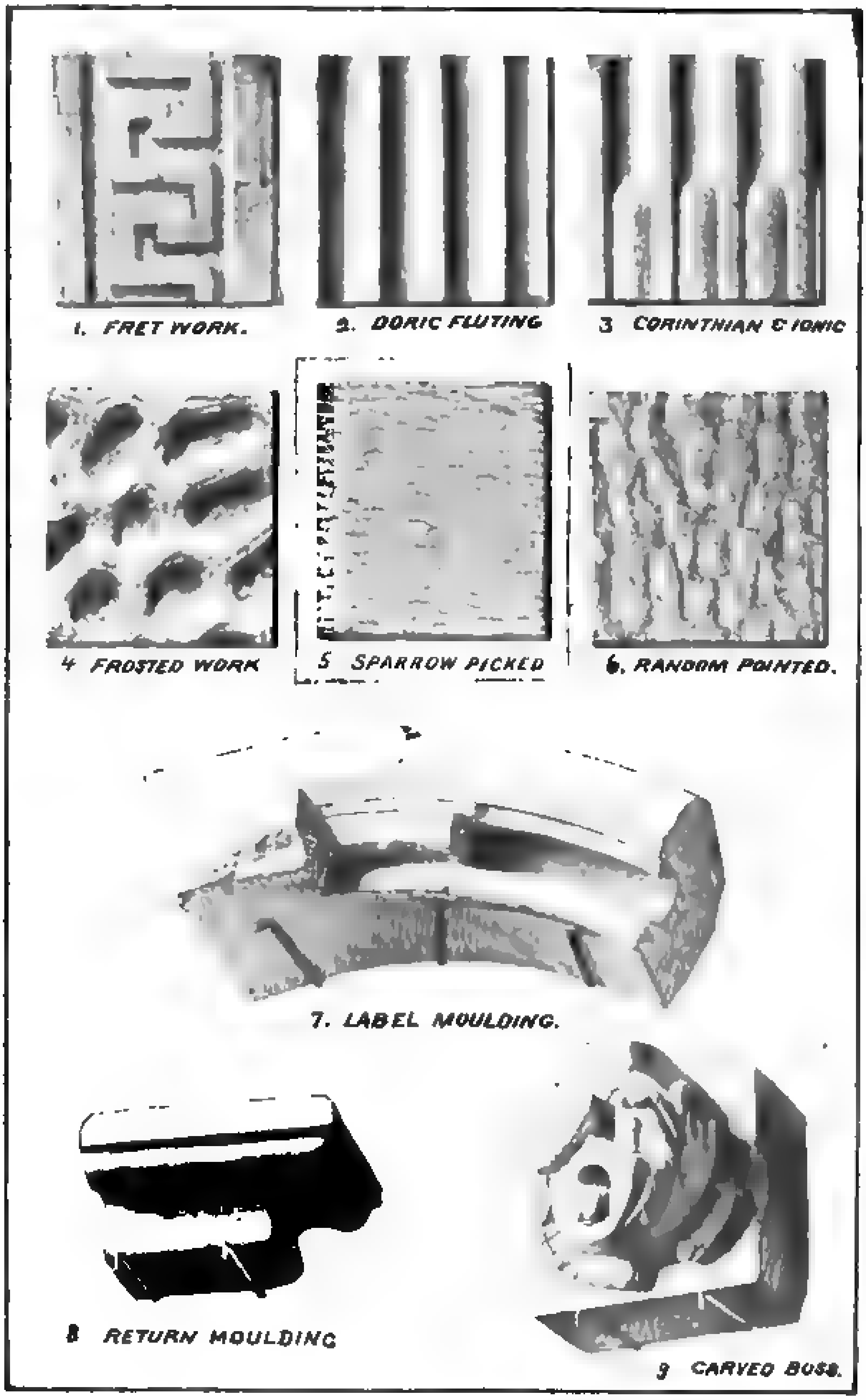
*The plate was kindly loaned to the Survey by the late Professor W. P. Trowbridge, who first used it in an article on stone-cutting in the School of Mines Quarterly for June, 1883.

†The description is copied from the School of Mines Quarterly, June, 1883.



KINDS OF FINISH. (Surfaces half the natural diameter; mouldings, one sixth.)

No. 5. *Sparrow picked.*—This is picked with a very small point and a mallet of about two pounds weight.

No. 6. *Random pointed ashlar.*

No. 7. *Label moulding.*—The first work on this stone is to take the front face out of winding by cutting four chisel-drafts on the margin of the stone, the width of chisel being three quarters of an inch. Then point off the waste down to one fourth of an inch of the draft level with a mallet-head point made out of three quarter-inch bar steel. Then take a large sized tooth chisel and chisel the whole surface. The stone-cutter then takes a large sized drove and droves it over perfectly straight and smooth, to suit a good straight edge. This face is then finished. Both the tooth chisel and the drove are two and one half inches wide, the pointing mallet four pounds weight, and the droving mallet six pounds weight.

The stone-cutter now takes the face pattern cut out of zinc, applies it to the chiseled face, and scribes the outline with a lead-pencil; he takes a drove and pitches off all waste outside of the lines; he turns up the convex side of the stone, which is supposed to be the top bed, and runs an arris-draft, keeping as close as possible to the pitched line. When this arris draft is complete it must fit the concave templet.

His next work is to run a draft on the bed at each end of the stone, at right angles to the face; then he points off the waste to the eye; he puts on his concave templet and tooth-chisels the bed with drafts until it fits the templet; he then takes his drove and droves it back from the face say four inches, to the projection line; past the wall line it does not need droving, for the rest of the bed is buried in mortar. This is a rule in all stone-cutting; no stone needs droving that is bedded in the wall. If lumps are left it is "nobled," that is struck in a few places where the eye judges there are lumps.

His next work is to square the meeting-joints. This is done by cutting the face arris-draft, then squaring down the depth of the joint with two chisel-drafts at right angles from the face, pointing off the waste of the intermediate, and then tooth-chiseling and droving it over. This is done for both joints.

Then the stone-cutter takes his section pattern in his left hand and applies it to the end of the stone. Keeping his fingers pressed tight against it (he must not let it slip) he calls on his nearest fellow workman to help him by holding a straight-edge on the face projecting over the end of the stone. He takes hold of the concave templet with his right hand and presses it on the top bed of the stone. He keeps the edges of the pattern pressing against the straight-edge and the concave templet; this will adjust the pattern. Then he scribes all of the outlines; he turns up the concave or setting-bed, runs a draft at each outline on this bed, the line being given by the section pattern. When these two drafts are complete he takes his No. 1 concave templet and applies it to the stone, cuts to suit the templet, and this bed is done. His next work is to draw chamfer lines on the ends of the stone tangent to the greatest number of members; then he cuts the chamfer or inclined plane. The chamfer is the most important of all the mouldings in stone-cutting; it shows every man in the business his way out; we cannot cut a common moulded step without chamfering. Very often stone-cutters commence racing on their work to show their strength and ability. It is then they will try to avoid cutting the chamfer and take a short cut. They who do this have not got a straight member, their work looks ridiculous, and is not fit to go into a building. The architect is blinded very often in this work; the stone-cutter is in a hurry, and will not adhere to the outlines given by the architect; probably when a scotia should have been sunk three fourths of an inch in the middle of a stone five feet long, the stone-cutter might not have sunk it to a depth of half an inch, but he is sure to have it right at the ends.

On the stone are shown the chamfer and the cutting lines of the solid of each member; also a portion of the mould finished, ready for rubbing. There is a templet to correspond with each cutting line on the face of the stone. When the stone is placed in working position, with its face uppermost, the templet is laid on the chamfer.

The tools used in moulding this stone are one half-inch and

one quarter-inch chisels, points being made out of three eighth-inch bar steel, and a moulding mallet of four pounds weight.

Four feet in length is a good day's work of this sort.

No. 8. *Return moulding.*—The first work to be accomplished on this stone is to cut the top bed by chiseling four drafts out of winding, then point off the waste or debris down to the level of the drafts, then use the pean ax on any lumps left by the hammer point. The tools used on this bed are a seven eighth-inch chisel, and a seven eighth-inch hammer point. Next turn up the intended face or front edge and run an arris-draft, making it wide enough to cover the top surface of the nose. Then square the ends or meeting-joints with right angles to the top bed and nose-draft.

When this is done apply the section pattern to the ends by keeping a straight-edge in one hand, say the right, and with your left hand pressing the pattern against the stone. Place the straight-edge on the nose-draft and keep the pattern up to it; then apply the straight-edge on the top bed in two or three places and bring the pattern flush to it, then scribe the whole outline of the pattern with a cast-steel pointed scriber or a piece of iron ore. When this is done on both ends of the stone, turn up the setting-bed and cut it to the given lines of the pattern. The top bed being cut out of winding, and the joints being cut at right angles to said bed, the same pattern being applied to both ends will give the setting-bed truly out of winding.

The next step is to draw such a chamfer line on the ends of the stone as is tangent to the greatest number of members, then cut to the lines, which will give a chamfer or inclined plane. Then the stone-cutter commences moulding. Working from right to left of the stone he completes all of this edge except the cove or scotia. He cannot cut this trough until the returned head is precisely as far advanced, because it is less than a right angle from the face of the stone.

His next work is to turn up the quoin end or returned head, chisel the nose-draft, square the adjoining end, and apply the pattern as usual. Then he has to find a mitre-line, the intersecting line of all the members. To do this he turns up the

setting-bed and draws two lines parallel to and equally distant from the two faces. A line drawn from the intersection of these lines to the intersection of the nose-drafts at arris will make an angle of forty-five degrees and be the true mitre-line of the stone. Then he has to mould the edge from the given mitre-line along the quoin. When this is done he turns up the setting-bed and cuts the scotia on the two edges. After being moulded with the chisels the patent ax is applied, and the moulding is done.

This stone is moulded with three quarter-inch and one half-inch hammer-head chisels and three quarter-inch and one half-inch points of bar steel. Two and a half feet length of this moulding is a good day's work for a stone-cutter.

No. 9. *Carved boss.*—This block has been cut into a solid cube previous to being rounded off, to receive free-hand pencilling. The operator bankers up the front face, takes it out of winding by four chisel-drafts—three quarter-inch chisel used—and then points off the waste to within one fourth inch of draft level. He then takes the largest sized tooth-chisel and a six pound mallet made of hickory wood, and chisels the face to a surface level with the drafts. He then takes the largest sized drove and with the same mallet droves the tooth chiselled surface over. Then, having finished the first work, he lays out the full size of his stone by drawing four lines to represent a square; from this plane he cuts the four sides, at right angles to it; the sixth side is left rough, being in the wall. The tools he uses on the squaring up of the block are points of three quarter-inch steel bar, three quarter-inch drafting chisels, droves, and tooth chisels two and one half inches wide, and a pointing or drafting mallet of four pounds weight.

His next work is to turn up the top bed. This block is of strata formation, and therefore it is most essential to have the bed of stone adopted by the stone-cutter the same as the natural bed. That side of the stone is always called by the stone-cutters the "free-way." So he will turn up the free-way for his top bed; the opposite is the setting-bed, which is the free-way also. He applies the label section pattern to the bed. This pattern projects, say four inches from the face of the wall; he pro-

jects the boss surface one inch outside of this, which leaves it five inches outside of the wall line. He draws a center line on the bed at right angles to the face and finds a point four inches in from face on this line, and with a radius of four inches he describes a semicircle. This is a cutting-line, to bring the projecting part of the stone into a semi-cylindrical shape. Then he bisects this cylinder with a pencil-line parallel with the horizon, and the lower portion he rounds off to a spherical shape, with a concave quadrant templet taken from a circle four inches in diameter. When this is done the stone is ready for free-hand pencilling, and when pencilled, he cuts the outlines of the leaves and gets them into shape; then he takes a splitter and relieves the stems, sinks the eye, splits open the spaces, and then he rolls the face of the leaves, and so on, till he suits the eye.

The tools generally used in carving are the splitters, one eighth, one fourth, one half, and three fourths inches in width at the chisel end, the plain chisels of the same width, hammer-head drills, and a three pound mallet.

Other kinds of finish not described above are pointed face, pean-ax, six-cut, ten-cut, twelve-cut tooled work, tooth chiselled, bush hammered, superfine bush hammered, fine droving, sand-rubbed, and polished. Some of these, however, are not used on marble or limestone but on granite or other hard rock*

Polishing.—The common method is to do the grinding on a large rubbing bed and the polishing either by hand or with a buffer. If all the work is done by hand the surface is first rubbed with sand, emery, chilled shot, or crushed steel, until all the large inequalities of the surface have been taken out. It is then rubbed with grit and smoothed down with pumice stone and Scotch hone, after which it is ready for the final gloss. Other materials are frequently used in this process, such as tripoli, rabat, Bath brick, fullers' earth, etc. It is sometimes necessary with certain colored marbles to go over

*A series of articles on stone-cutting, by D. F. Kennedy, valuable to the practical stone-cutter, is published in Stone, Indianapolis, beginning with December, 1890.

them at this stage and fill all the flaws with a mastic the color of the stone, the process being called filling. The final gloss is put on with putty powder which is rubbed with a linen or felt cushion and plenty of good hard rubbing is necessary to make this perfect. Alum or oxalic acid is used by some to hasten the process, but their use should be condemned because both are injurious to the stone and the polish is not lasting. Most of the so-called lightning polishers contain acid. It is the polish which distinguishes the marble from common limestone and the value of marble depends in large measure on the kind of polish it will take.

APPENDIX.

CHAPTER XXIX.

THE FAULTS OF THE MARBLE REGION OF NORTH ARKANSAS.*

The rocks throughout the marble region of North Arkansas are for the most part horizontal; to this rule there are but few important exceptions, and in the exceptions the bending of the beds is comparatively gentle.

Faults, however, have performed a prominent part in the disturbance of the horizontality and continuity of the strata of the region in question. In some places these faults are of but local importance, while in other cases a single break may be traced almost continuously for thirty miles or more.

The throw of the faults though never very great, is sometimes 400 feet or more—sufficient often to carry the marble bed down on one side out of sight and quite out of reach for all practical purposes. The character of the folds found in the vicinity of the faults is sufficiently well shown in the accompanying cuts and plates to require no further explanation in this place.

Attention should here be called to the relation of the two faults near St. Joe; that to the north has the downthrow on the south side, while that to the south has the downthrow to the north side. This relation of these parallel faults continues for miles. Along this distance it thus appears that a block of the earth's crust less than a mile wide has dropped down 100 to 400 feet along a distance of many miles.

The faults here spoken of all occur in rocks of the Silurian and Lower Carboniferous ages; so far as has been determined

*Only such of Mr. Hopkins' observations on faults as bear directly upon the geology of the marble beds are given here; others will be given in the final report.

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none of the rocks affected by the faults here spoken of are of later age. Other peculiarities of the individual faults will be spoken of in connection with the description of each one.

Faults in Independence county.—About two miles north of Batesville, near where the Polk Bayou road crosses the bayou the first time, is a double fault, the downthrow in both cases being on the south side.*

The railway west of Batesville crosses the line of a fault a few yards south of the crossing of the Batesville-Mountain View road. From the railway the fault may be traced southwest to the bluff on the east bank of Spring Creek, west of which it is concealed by alluvial deposit.

Two miles west of this place, near the centre of the southeast quarter of section 15 (13 N., 7 W.,) a fault was observed with the downthrow on the south side. The direction of the line of fracture here is not clearly defined. East of the railway the line of fracture is indicated by the Batesville sandstone on the south side and by the Boone chert debris on the north side. The fault crosses the wagon road less than a quarter of a mile east of the railway and is but a few yards north of the wagon road at the top of the hill, more than half a mile from the railway. This fault seems to be on the same line of disturbance as the one on Polk Bayou and the one described by Dr. Penrose at the Cason mine.†

Faults in Stone county.—On Roasting-ear branch of South Sylamore, 15 N., 12 W., section 7, the northeast quarter, at the mouth of a ravine near Mr. Stephens' house, a fault occurs where the Boone chert on the north side of the fault abuts against the Izard limestone overlain by St. Clair marble and chert on the south side. Owing to the abundant chert debris the displacement could not be measured; it is estimated at about 100 feet. This fault is visible on the hillside east of the ravine and may be traced across the north part of section

*For illustration and description, see Vol. I. of the Annual Report of the Geological Survey of Arkansas for 1890, p. 110.

†Op. cit., pp. 110, 120.

7 in a nearly due west direction. It was not located west of section 7.

Fault in Baxter county.—On Spring Creek in Baxter county, in 16 N., 13 W., about two miles northeast of Big Flat, is a fault with the downthrow of 200 or 300 feet on the southwest side. The Boone chert occurs along the creek bank above the crossing of the Big Flat-Mountain Home road. The hill on the south side of the creek is composed of the chert, and capped with the Batesville sandstone. On the north side of the creek is an exposure of 250 feet of Silurian rocks overlain with chert. The details of the fault on Spring Creek were not traced out, but occurring, as it does, almost directly between the one on Roasting-ear Creek, and the one on Rush Creek, it is possibly in the same line of disturbance.

The Rush Creek fault.—The greatest faults and folds occur in the valley of the Buffalo River. No less than eight faults have been noted in the immediate bluffs of the river, and there are many others more or less remote from the stream.

The fault on Rush Creek follows closely the course of the stream. It has been traced from near the mouth of the creek in 17 N., 15 W., section 12, the southwest quarter, to section 6, the north part. Figure 12 shows a section across the fault at Rush post-office where the throw is about 260 feet.

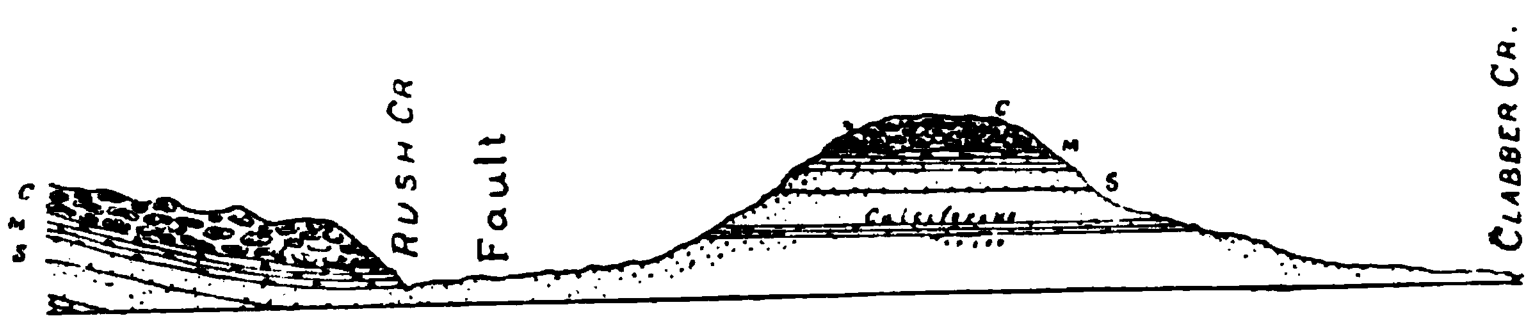

FIG. 12. *Fault on Rush Creek.*

C, Boone chert. M, St. Joe marble.
S. Saccharoidal sandstone and underlying rocks. Scale: one inch = 1000 feet.

On the south side of the creek the Silurian sandstone overlain by St. Clair marble and St. Joe marble outcrops on the creek bank, and in the ravine opposite the post-office the rocks dip north at an angle of from two to ten degrees. On the north side of the creek the St. Joe marble outcrops near the top of the hill above the zinc mines. The fragmental condition of the rocks

in the valley obscure the line of fracture. The fault continues in the valley below the post-office for half a mile or more, and becomes concealed by chert debris in the hill on the south side of the creek near its mouth.

Up Rush Creek from the post-office the fault is shown by the continuation of the hill of Silurian rocks on the north side, and the Carboniferous rocks on the south side. The line of fracture is shown in some of the lateral ravines that enter from the south.

Water Creek faults.—Two faults cross Water Creek in 17 N. 16 W., in a northeasterly direction. The lower one of the two is in 17 N., 16 W., section 35, 100 yards west of the point where the St. Joe-De Soto (Sylva) road crosses the creek. The downthrow is on the southeast side, and the displacement is about 100 feet. The fault is shown by the red marble occurring in the creek bed near the wagon road on the southeast side of the fault, and by the same rock occurring more than 100 feet above the creek on the north side of the fault. The fault seems to run south 35° west, as it occurs in section 34, the southeast quarter, in the ravine from the south, opposite the widow Langston's; the wagon road in this ravine follows the line of the fault for 100 yards or more, with the limestone and marble exposed on the north hillside, and the Boone chert on the south hillside. The chert debris on the slopes prevents the tracing of this fault out of the Water Creek valley.

Another fault in the Water Creek basin is near the head waters of that stream and crosses not less than three of the terminal ravines. It is quite prominently marked about 100 yards west of the St. Joe-Yellville road in 17 N., 17 W., section 25, the southeast quarter. Immediately south of the fault the Boone chert is the only rock exposed, but the St. Joe marble outcrops underneath it 400 yards further down-stream. On the northwest side of the fault the Silurian sandstone and limestone are exposed much crumpled and twisted. The chert debris obscures the fault on the tops of the hills on each side of the creek, but that the fault on Barren Fork of Water Creek in 17 N., 16 W., section 21, the northeast quarter, is a continu-

ation of the same fault, is shown both by the direction and throw being the same, and by the continuity of the marble outcrop at the same general level around the heads of the ravines on the northwest side and the occurrence of the same rock in the creek bed on the southeast side. The marble on the hill on the northwest side of the fault is 220 feet higher than that in the creek bed on the southeast side, but as the two points measured are more than a mile apart the actual displacement in the rocks may be more or less than this.

The Tomahawk faults.—Prominent faults are noted at four places in the Tomahawk Creek basin. The lowest one in the valley is in 16 N., 16 W., sections 15 and 16 on the lower part of Mud Spring Branch. Its direction is a little north of west and its downthrow is on the south side. South of the fault the Boone chert is the only formation exposed; north of it the saccharoidal sandstone (Silurian) overlain by marble and chert forms a prominent ledge along both sides of the ravine for more than a mile.

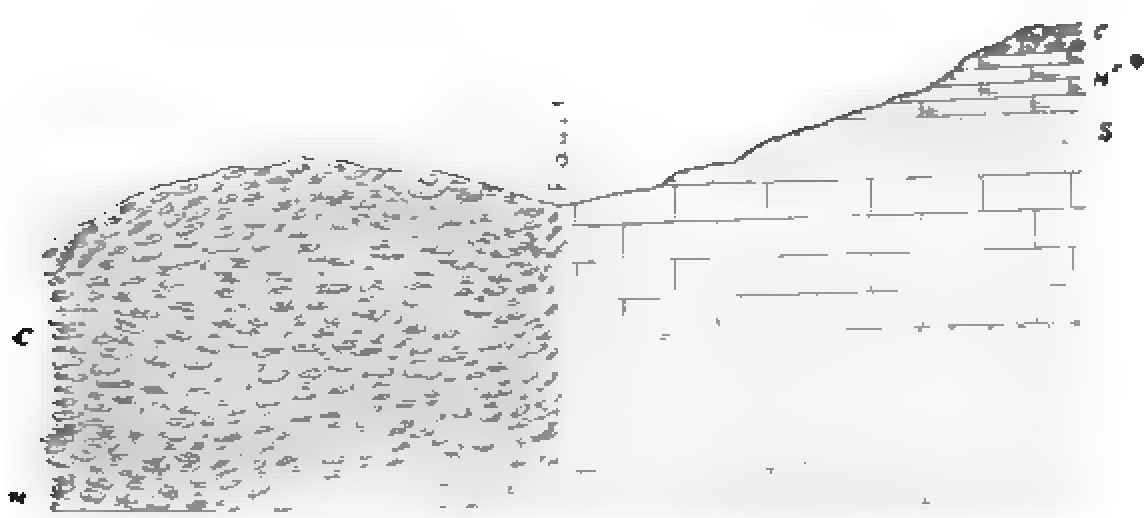

FIG. 13. *Section across fault on Buffalo River near the mouth of Tomahawk Creek.*
C, Boone chert. M, St. Clair marble
S, Saccharoidal sandstone. M', St. Joe marble.
Scale: one inch=100 feet.

The best section across this fault, as shown in fig. 13, is found on the river bluff just east of Mud Spring Branch in the southwest quarter of section 15, 16 N., 16 W. The marble (M) exposed at the base of the hill on the south side of the fault is

the St. Clair (Silurian), the St. Joe marble, if present, being concealed by the chert debris. On the north side of the fault more than 250 feet of Silurian rocks (S) are exposed with the St. Joe marble (M') near the top of the hill covered with a thin bed of chert (C). The section shown on the illustration, was taken on the west bank of Buffalo River on the outside of the horse-shoe curve about half a mile down-stream from the mouth of Tomahawk Creek; a bridle path up the bluff from the river is very nearly on the line of the fault.

In 16 N., 16 W., section 8, the southeast quarter of the northwest quarter, in a little ravine from the northwest at Mr. Parks' house is a fault running in a nearly east-west direction with the downthrow on the south side. Plate XVI., facing p. 296, shows a section across the fault near the mouth of the ravine, with the ravine in the background. The watercourse follows the line of the fault, the slope on the south side being covered with black Marshall shale and Batesville sandstone bowlders, the slope on the north side showing outcrops of St. Joe marble, Boone chert and cherty limestone. The same fault, exhibiting similar phenomena, occurs a short distance west, in the small ravine flowing west to the old copper smelter in the north part of section 7. The fault passes about 100 yards north of the old smelter, and south of the copper mine it is marked in a general way by the bed of black shale on the south side and the Boone chert or Silurian sandstone on the north side. Faulting also occurs at the copper mine, the throw being much less than in the fault south of the mine, possibly being part of the same break. The same line of disturbance occurs just south of Richard Thompson's house in 16 N., 17 W., section 1, the southwest quarter, but whether at this point it is a fault or a steep monocline was not ascertained.

At Gaines' Spring on the hill west of Tomahawk Creek in 16 N., 17 W., section 2, the south part, is a fault, with the downthrow on the south side. On the north side of the fault a few yards north of the spring the following section is exposed, the rocks being in a nearly horizontal position:

Section on Tomahawk Creek at Gaines' Spring.

	feet.
Boone chert and limestone	120
St. Joe marble	30
Silurian sandstone and limestones	130

On the south side of the fault the spring emerges from a broken mass of Boone chert and limestone which stands at high angles, varying from nearly 90 degrees at the fault to a nearly horizontal position in the little valley from the west less than half a mile south of the spring. The line of fracture is quite plain where some digging by prospectors has been done on the line of the fault. On the hill west of the spring the rocks are much broken.

Another fault crosses Tomahawk Creek just above the mouth of Pine Hollow in 17 N., 17 W., section 35, the southeast quarter. As in all the faults on Tomahawk Creek the down-throw is on the south side, the vertical displacement in this case being about 160 feet. The measurement from the bottom of the marble on the south side at the mouth of Pine Hollow to the same point on the north side is 200 feet, but as shown on the accompanying figure (14) the rocks on the south side have a strong dip to the southeast, so that the actual displacement is less than 200 feet. A good section across the same

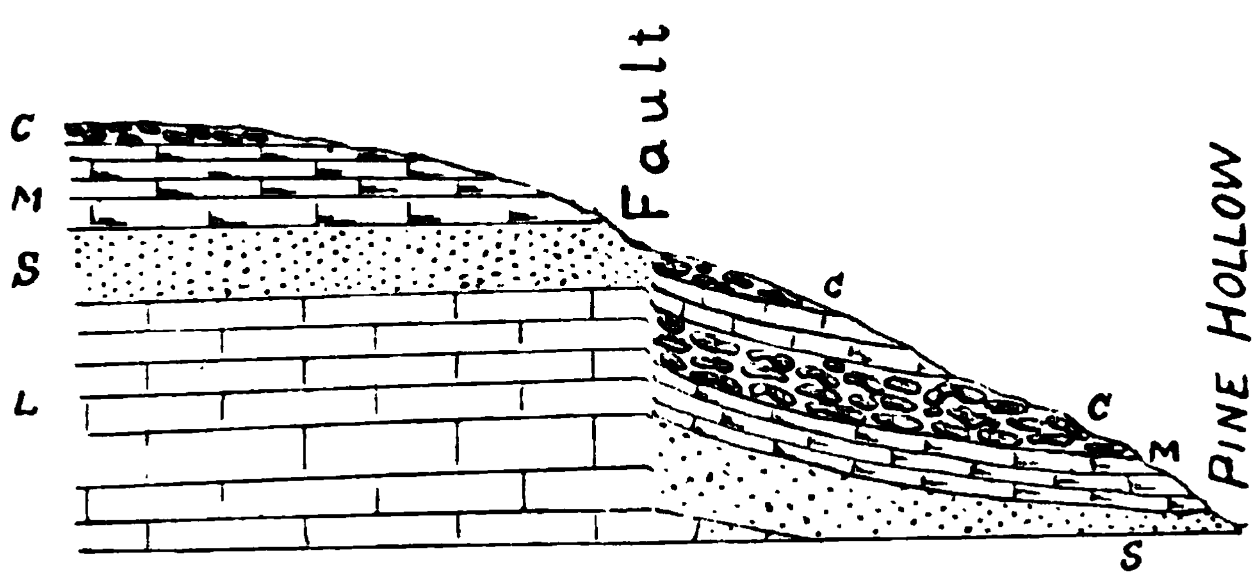

FIG. 14. *Section across fault on Tomahawk Creek at mouth of Pine Hollow.*
C, Boone chert. M, St. Joe marble.
S, Saccharoidal sandstone. L, Silurian limestone.
Scale: one inch = 266 feet.

fault may be seen in a lateral ravine from the northwest half a mile up Pine Hollow, where the ravine crosses the fault

at nearly right angles, with an outcrop of Silurian rocks overlain by red marble and chert on the north side, and the Boone chert in the bottom of the ravine on the south side of the fault.

A fault occurs in 16 N., 17 W., section 9, at the head of Granny Thompson Hollow, a small tributary of Tomahawk Creek. The Batesville sandstone and Marshall shale outcrop on the south side of the fault and the Silurian sandstone overlain by the red marble and Boone chert on the north side. The line of fault is on the south side of the ravine at the head, but from a quarter to a half mile east from the head of the ravine the line of fracture crosses to the north side where it is obscured by rock fragments on the hill in sections 3 and 10.

The St. Joe fault.—The St. Joe fault is about one mile north of the village of St. Joe on the south slope of the dividing ridge between Mill Creek and the south prong of Tomahawk Creek and runs in a nearly east-west direction. The village of St. Joe is on the Batesville sandstone, which, with the overlying shale, extends to the monoclinal fold that lies south of the fault. Figure 15 shows a section from St. Joe to the top of the hill north of the village through both the monocline and the fault. The downthrow is on the south side; a line of levels run by the State Geologist shows the displacement to be 283 feet.

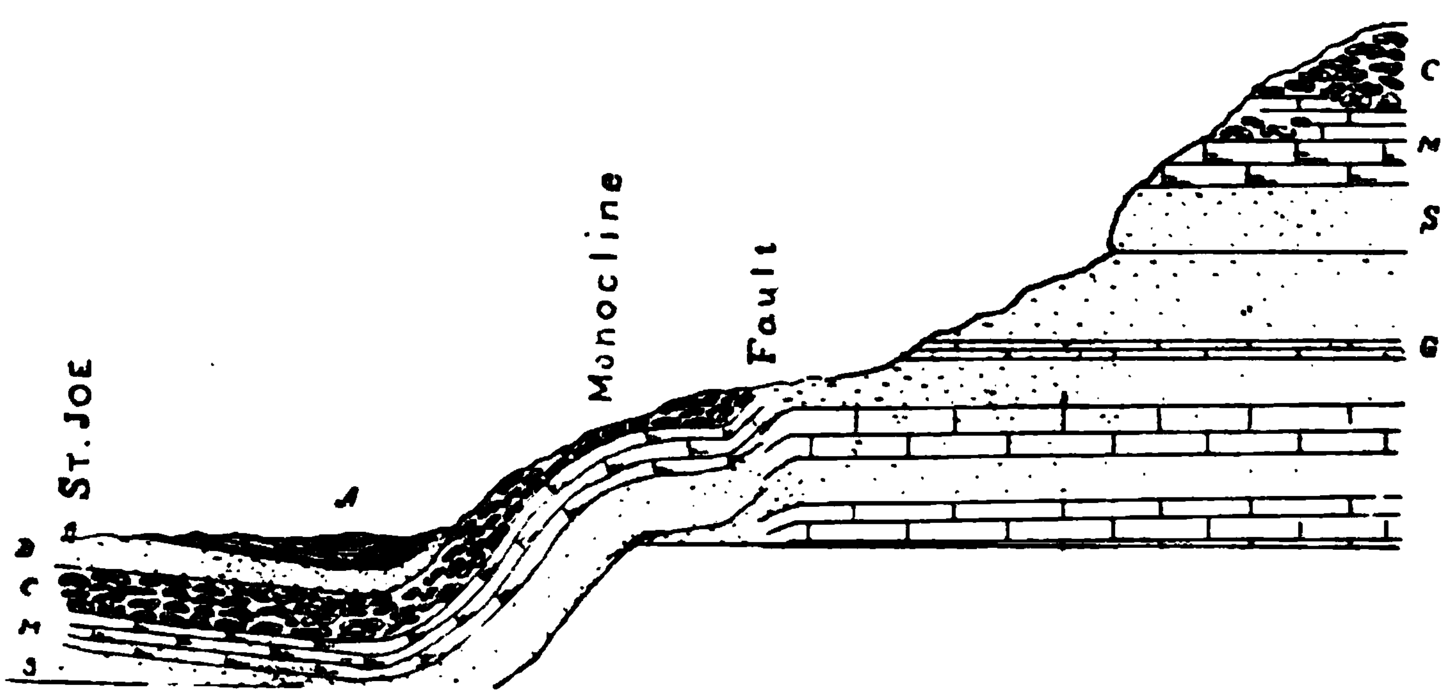

FIG. 15. *Monocline and fault at St. Joe.*

A, Marshall shale.
B, Batesville sandstone.
C, Boone chert.
M, St. Joe and St. Clair marbles.
S, Saccharoidal sandstone
G, Calciferous rocks.

From the zinc mines near St. Joe the fault can be traced east as far as the head of the ravine on the west side of section 9 (16 N., 17 W.), where it is concealed by the chert debris; the fault and monocline appear to meet near the head of this ravine. The wagon road from St. Joe to South Tomahawk Creek crosses the fault 200 feet above the valley and between a quarter and a half mile north of Mr. Turney's house.

Westward the fault was traced into 16 N., 18 W., section 11, the south part, a distance of two miles. It runs very nearly parallel with and from a quarter to a half mile north of Mill Creek. The old Carrollton road crosses the fault 285 feet above the creek. West of the road the fault can be located very accurately in the numerous ravines leading into Mill Creek from the north, by the actual contact of the rocks, and on the dividing ridges between these ravines by the line between the broken chert on the south side and the broken sandstone on the north side. Fig. 16 gives a north and south section across Mill Creek in 16 N., 17 W., west part of section 7, half a mile or more west from the forks of the creek, which shows the relation of the rocks at this fault and at the one on the south side of Mill Creek.

The Mill Creek fault.—Another fault has the same general direction on the south side of Mill Creek that the St Joe fault has on the north side. A section across it is shown in Fig. 16,

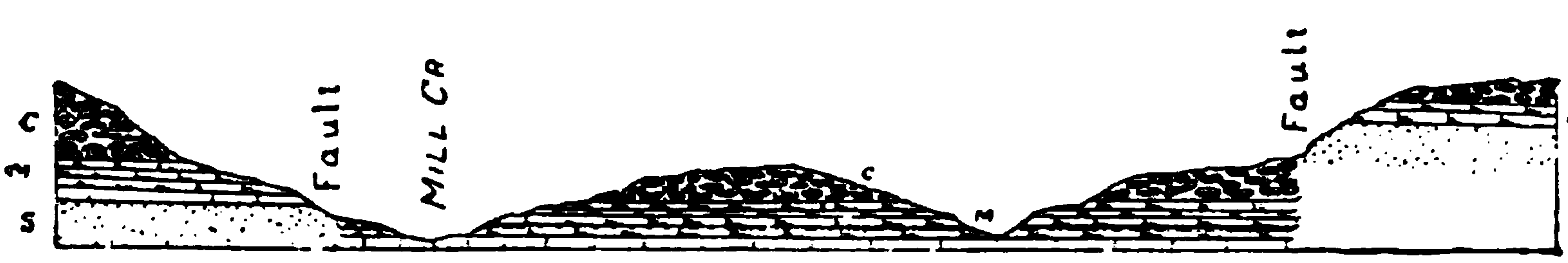

FIG. 16. *Faults on Mill Creek, west of St. Joe.*
C, Boone chert. M, St. Joe marble. S, Saccharoidal sandstone.

where the displacement is 100 feet with the downthrow on the north side. It will thus be seen that Mill Creek, in this part of its course, runs along and close to the southern limit of a depression. The most eastern exposure of the Mill Creek fault is about half a mile west from the forks of the creek on the hill on the south side of the creek in 16 N., 17 W., section 18, where

the red St. Joe marble on the north side of the fault, may be seen in direct contact with the saccharoidal sandstone on the south side. The displacement (100 feet) was measured from the bottom of the red marble in the ravine near the creek on the north side of the fault to the bottom of the red marble on the hill on the south side of the fault. The fault can be easily traced westward along the south side of Mill Creek to near the middle of section 14 (16 N., 18 W.). While it is obscured on the hillside in many places by the chert debris, it is very distinct in the numerous ravines on the south side of Mill Creek.

The Caney Creek fault.—A fault crosses Caney Creek near its head and less than a quarter of a mile south of the Marshall and Harrison road, 16 N., 18 W., close to the section line in the south part of section 8, where three short ravines unite. It has a nearly east and west direction with the downthrow on the north side. On the north side of the fault is the gray marble of the Boone chert series overlain by the chert; in the watercourse abutting against this on the south side is the saccharoidal sandstone of Silurian age, which on the hillsides is overlain by the St. Joe marble and Boone chert. The displacement is estimated to be from 80 to 100 feet.

The Davis Creek faults.—On Hurricane branch of Davis Creek, in 16 N., 19 W., sections 11 and 12, are two faults. The first one, in the southwest quarter of section 12, and in a branch ravine in the southeast quarter of section 11, has the same direction and throw as the first one described on the head of Caney Creek. The Silurian sandstone outcrops in the creek on the south side of the fault, and the red marble on the north side.

About half a mile north of the fault last described is another one, with the downthrow on the south side, which has nearly the same general east and west direction. At the head of Hurricane Branch, in 16 N., 18 W., the north part of section 7, the line of fault is nearly identical with the watercourse. Through section 12 (16 N., 19 W.), the fault, which runs in a nearly west direction, is north of the ravine which has a nearly southwest course. It is marked by the Boone chert outcrop

on the south side of the break, abutting against the Silurian sandstone on the north side.

On another tributary of Davis Creek, in section 10, (16 N., 19 W.), is a fault with the same direction and throw on the same side as the last one above. Another similar one, or a continuation of the same, crosses Davis Creek, in section 9 (16 N., 19 W.), where the chert outcrops on the south side of the fault, while 100 yards or more down the creek from the fault the marble outcrops at the water level, but rapidly rises to near the tops of the hills. On the north side of the fault the marble outcrops near the tops of the hills, but dips north five to ten degrees, so that it is at the water level at Yardell.

Through section 9 and the northeast quarter of section 8 (16 N., 19 W.), the fault may be traced by the broken chert on the south side and the broken saccharoidal sandstone on the north side.

Faults on Big Buffalo River.—Below the mouth of Mill Creek, in 16 N., 20 W., section 5, in the bluff on the north side of Big Buffalo, 200 to 300 yards east of the Jasper-Marble City road, is a compound fracture in the rocks, the details of which are shown on Plate XV., facing p. 280. The most prominent break is the one on the right of the figure and lowest on the river. The downthrow is on the northwest side where the red marble is exposed at the water's edge; on the southeast side is an exposure of 35 feet of Silurian sandstone which is overlain by the red marble and chert. The breaks above and west of the ravine are not so conspicuous, and the displacement not so great.

On the north side of Big Buffalo, in 16 N., 22 W., there is a fault just north of the quarter section corner on the line, between sections 10 and 11 on the steep slope on the north side of the road, about 200 yards from the ford. The downthrow is on the south side, and the vertical displacement is probably nearly 400 feet. The Boone chert occurs on the south side of the fault on the point of the hill and in the valley; the Silurian sandstones and limestones on the north side,

outcrop 350 feet above the road, thus showing the displacement to be more than 350 feet.

A fault of similar nature, which is possibly a continuation of the same, occurs in the east side of section 9, near the mouth of Sneed's Creek. The mouth of Sneed's Creek is on the Silurian rocks which have an exposure of nearly 300 feet at the mouth of the creek. A hundred yards up-stream from the mouth of the creek the Boone chert of Carboniferous age outcrops at the water level.

Half a mile up-stream from the mouth of Sneed's Creek, on the west side of the river, and a hundred yards below the second ford of the river above Sneed's Creek, is another fault with the downthrow on the north or east side. On the east side of the fault the strata dip down the river so that the saccharoidal sandstone which is exposed at the fault disappears a hundred yards down-stream. On the west side of the fault is a high bluff of Silurian rocks, the upper part of which is composed largely of saccharoidal sandstone. The displacement is 350 feet or more.

A fault occurs on Sneed's Creek, in the south part of section 5 (16 N., 22 W.), near where the road to Compton post-office leaves the creek. The downthrow is on the south side. A fault was observed on Sneed's Creek above this, possibly in the southwest quarter of section 5, which crosses Sneed's Creek at a low angle, the downthrow being on the south side with the Boone chert outcropping; while on the north side of the fault the saccharoidal sandstone is exposed 100 feet or more, overlain by marble and chert.

Faults on Little Buffalo River.—Numerous prospecting shafts are sunk along the line of a fracture that occurs in 16 N., 21 W., section 31, in 16 N., 22 W., section 36, and 15 N., 22 W., sections 1, 2, and 11. In some places, as at the Panther Creek mine, the displacement appears to be horizontal, as the striæ on the slickenside walls are horizontal, and no evidence can be seen in such places of any vertical displacement. In other places a vertical displacement is quite plain, as in the south part of section 36 (16 N., 22 W.), where on the hill above an

outcrop of 100 feet of Marshall shale is an exposure of 100 feet or more of Boone chert, an underlying formation. At Blue Bluff, 15 N., 22 W., section 1, the southeast quarter of the northwest quarter, the fault has a downthrow of ten to fifteen feet on the southeast side.

The Green Forest monocline.—A large monocline, in general direction south 15° east and dipping north 75° east, occurs in ranges 23 and 24, crossing the Harrison-Eureka Springs road, two miles west of Green Forest. Faults occur in places along this monocline.

It is noticeable in traveling the road from Harrison to Berryville by the general geologic features. From Batavia to Green Forest, by way of the lower or Terrapin road, one is almost constantly in sight of a prominent ledge of rocks, the Millstone grit, south of the road and several hundred feet above it. West of Green Forest this ledge disappears, and two miles west of Green Forest another ledge appears, which is not so thick nor so near the tops of the hills as the other and is composed of the St. Joe marble, a formation which occurs geologically several hundred feet below the Millstone grit.*

This monocline is likewise conspicuous on a geologic map. (See Carrollton map-sheet.) The large Silurian exposure of the King's River and Osage Creek valleys has no counterpart in the Long Creek valley to the east, which would be the case if the rocks were horizontal or nearly so. Likewise the Batesville sandstone and Millstone grit areas about Green Forest have no counterparts on the equally high hills west of Green Forest and west of Osage Creek.

While no clearly defined lines of break of any extent were located along the line of Green Forest monocline, it is evident that the rocks are more or less faulted a part of its length. The most southern point noted on the monocline is in 18 N., 23 W., section 15, at the spring from the base of the marble bluff on the east side of the wagon road, and for half a mile or more south of the spring in the valley. It is probable, however, that this is not the southern limit of it.

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*See p. 10.

In 18 N., 23 W., section 3, on the south side of the small tributary from the east the monocline is shown by the ledge of saccharoidal sandstone which has a dip of 18 degrees a little north of east.

In 19 N., 23 W., section 20, on the road from Green Forest to Rule post-office on top of the divide between Yocum and Osage Creeks, there is apparently a fault in the rocks. The Boone chert outcrops on the west side of the road, and the Batesville sandstone on the east, overlying which, and not more than fifty feet above the road is an outcrop of Millstone grit. North from the top of the ridge towards Green Forest, the road descends 420 feet over the Batesville sandstone, the line of parting between the chert and the sandstone lying west of the road, and for more than half a mile in sight of the road. The dividing ridge between Yocum and Osage Creeks, through sections 7 and 18 (19 N., 23 W.) is a chert ridge 400 feet higher than the gently undulating region about Green Forest, which is on the Batesville sandstone, the formation overlying the chert. The total change of level produced in the strata at Green Forest is not less than 450 feet, and is probably more than 500 feet.

In 20 N., 23 W., section 31, the marble outcropping in the watercourse near the middle of the west side of the section is 200 feet below the marble outcrop in the southwest corner of the section, the latter outcrop occurring in horizontal layers, the former dipping ten to twenty degrees nearly east. The outcrop in the watercourse in section 30 (20 N., 23 W.) has a similar sharp dip to the east, and is 350 feet lower than the marble outcrop on Pilot Mountain, in 20 N., 24 W., section 24.

The monocline crosses the Berryville-Springfield road in 21 N., 24 W., section 36, in a ravine a quarter to a half mile east of Indian Creek.

Faults in War Eagle Creek valley.—In the War Eagle Creek valley, in the south part of 17 N., 26 W., the rocks are much disturbed and faulted in a number of places; all the faults so far observed have the downthrow on the south side, and most

of them occur near the northern limits of the Batesville sandstone.

In 17 N., 26 W., section 25, the northeast quarter, a quarter of a mile west of War Eagle Creek and immediately west of the Huntsville-Marble road where it turns east, is a fault with the Batesville sandstone on the south side and the Boone chert on the north side, with a clearly marked dividing line between the sandstone and the chert traceable from the valley to the top of the hill.

A fault with similar throw but indistinctly marked occurs in section 23, the southeast quarter; another in section 22, the southeast quarter, where the line of fault is in the Holman Creek valley with the chert forming the hill on the northwest side and the Batesville sandstone on the southeast side.

In section 28 (17 N., 26 W.), the southwest quarter, northeast of the Hindsville-Huntsville road, is a fault with the Marshall shale on the south side in the valley and the Boone chert on the north side extending to the top of the hill. A displacement occurs on the west bank of Holman Creek in section 32 (17 N., 26 W.), in the southeast quarter.

Faults in upper White River valley.—In the White River valley below its confluence with War Eagle there is a fault on the east prong of Little Clifty Creek, in 19 N., 27 W., section 17.

A fault occurs in the Brush Creek valley, in 17 N., 27 and 28 W., extending into 16 N., 27 W. As in the Mill Creek valley west of St. Joe, there are two faults or fractures running nearly parallel with each other, the northern one having the downthrow on the south side, the southern one having the downthrow on the north side. In some places both fractures are on the same side of the creek, but generally the creek flows between the faults. In most places the lines of fracture are concealed by the fragmentary condition of the rock, yet the presence of the fault is shown by the strip of Batesville sandstone and Fayetteville shale in the bottom of the valley and the hillsides on each side composed of Boone chert, the higher parts of the hills being capped with the Batesville sandstone. This is illustrated in figure 17, which shows a section across the

faults on the road from Macedonia church to Fayetteville, from a quarter to a half mile southwest of the church, in 17 N., 28 W., section 22. One hundred yards south of Brush Creek the road passes from the Boone chert to the Batesville sandstone where in the ravine east of the road the chert, sandstone, and shale dip west of south at an angle of 45 degrees and are more

FIG. 17—*Section across faults on Brush Creek.*
B, Batesville sandstone and Marshall shale. C, Boone chert.

or less fractured. West of the road the line of contact of the sandstone on the south side and the chert on the north side may be traced up the hillside 100 feet or more above the valley and was traced a mile west of the road to near the half mile line in the south side of section 16.

On the Goshen road a quarter to a half mile southwest from the ford of Brush Creek the strata have a sharp dip to the north and are also faulted with the downthrow on the north side. The fault is shown directly by the Batesville sandstone abutting against the Boone chert and indirectly by the high chert hill to the south, capped with the same bed of Batesville sandstone that at the fault appears in the valley nearly 200 feet lower.

The fault was traced to 16 N., 27 W., section 5, the northwest quarter, where it is concealed by debris. The big spring at Mr. Parish's in the northwest quarter of section 5, is close to the south fault line, which is quite plain in the ravine west of the spring where the Batesville sandstone and black shale occur on the north side of the fault and the Boone chert on the south side. On the north side of Brush Creek opposite the spring, in 17 N., 27 W., section 33, is the north line of fault, the

reverse of the one at the spring, with the sandstone and the shale on the south side and the Boone chert on the north side.

Elixir Springs fault.—At Elixir Springs, in 20 N., 19 W., section 36, is a fault apparently local in extent. It shows on the west side of the ravine opposite and a little below the post-office, but does not appear on the east side, probably being concealed by the debris. The downthrow is on the south side, the displacement being from 50 to 75 feet.

THE END.

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